PROCEEDINGS

OF THE

AMERICAN PHYSICAL SOCIETY.

MINUTES OF THE ANNUAL MEETING, CHICAGO, DECEMBER 28–30, 1920.

THE twenty-second Annual Meeting (the 106th regular meeting) of the American Physical Society was held in Chicago, on December 28, 29 and 30, 1920, in affiliation with Section B—Physics—of the American Association for the Advancement of Science. The meetings were held in the lecture room of the Kent Chemical Laboratory of the University of Chicago. The attendance was between 200 and 300. On the evening of Tuesday, December 28, there was a Physical Society dinner attended by about 180 members and friends.

The President of the Society, J. S. Ames, presided at all sessions of the Society.

On the morning of Wednesday, December 29, there was a joint session with the Optical Society of America. The members of the American Astronomical Society were also in attendance. The presiding officers were F. K. Richtmyer of the Optical Society and J. S. Ames of the Physical Society. At this session the members of the Optical Society contributed three papers to the program as follows:

Photographic Reproduction of Tone. LLOYD A. JONES.

The Spectral Distribution Required to Evoke the Gray Sensation. IRWIN G. PRIEST.

The Propagation of Light in Rotating Systems. L. SILBERSTEIN.

A special feature of the program was a paper by Prof. A. A. Michelson on "The Application of Interference Methods to Astronomical Measures." There were seven other papers from the program of the Physical Society which are mentioned below.

On the afternoon of Wednesday, December 29, there was the General Interest Session of Section B of the American Association for the Advancement of Science. The chairman of Section B, Prof. J. C. McLennan, being absent, a former chairman, Dayton C. Miller, presided. The retiring chairman of the Section, Prof. Max Mason, gave an address entitled "From Oersted to Einstein." This address will be published in full in *Science*. This was followed by a symposium on recent progress in magnetism, consisting of the following papers:

The Electron Theory of Magnetism. S. J. BARNETT.

Magnetic Susceptibilities. S. R. WILLIAMS.

The Ring Electron. A. H. COMPTON.

The regular annual meeting of the American Physical Society was held on Thursday morning, December 30, 1920, at 11 o'clock. A canvass of the ballots for officers resulted in the elections of the following officers for the year 1921:

For President: Theodore Lyman.

For Vice-President: Charles E. Mendenhall.

For Secretary: D. C. Miller.

For Treasurer: G. B. Pegram.

For Members of the Council, four-year term: K. T. Compton, H. M. Randall.

For Members of the Board of Editors of THE PHYSICAL REVIEW, *three-year term:* G. S. Fulcher, F. A. Saunders, O. M. Stewart.

At the meetings of the Council held on December 28 and 30, 1920, the following elections were made: *Elected to Regular Membership*, F. O. Anderegg, C. A. F. Benedicks, C. W. Heaps, Ludwick Silberstein, F. E. Smith, Wilhelm Stenström, M. S. Van Dusen, E. P. Warner, and A. W. Rowe; *Elected to Associate Membership*, Erik Andersen, Evald Anderson, P. G. Andres, A. A. Bacon, Edward Bennett, A. H. Bucherer, E. K. Chapman, J. F. H. Douglas, H. M. Elsey, J. E. Fox, J. G. Frayne, P. W. Froebes, D. K. Gannett, Pierre Haynes, J. R. Hobbie, Victor A. Hoersch, L. L. Holladay, F. M. Kamrenstine, J. A. Kiefer, A. L. Kimball, Jr., E. H. Lange, E. M. Lowry, L. E. McAllister, B. F. Miessner, Takeshi Nushi, A. L. Ondrak, T. D. Phillips, J. H. Pruette, Ben Rosen, L. Schmiedeskamp, K. F. Sun, V. F. Swaim, C. G. Thompson, L. A. Turner, C. L. Utterback, M. S. Waddell, A. E. Woodruff, B. C. Zimmerman, W. A. Zinzow, C. G. F. Zobel; *Transferred from Associate to Regular Membership*, H. L. Howes, E. O. Hulburt, Enoch Karrer, Benjamin Liebowitz, H. W. Nichols, and H. C. Rentschler.

The secretary reported the death of six members, and the resignation of eleven members. The membership at the present time consists of 7 honorary members, 456 regular members, and 833 associate members, making a total of 1,296.

The regular scientific program consisted of 69 contributed papers, five being read by title, this being the largest program in the history of the Society. The abstracts of all the papers will be found on the succeeding pages. The program was as follows:

The Resistance of a Compressible Fluid at High Velocities. L. THOMPSON.

The Thermal Expansion of Nickel, Monel Metal, Stellite, and Stainless Steel. WILMER SOUDER and PETER HIDNERT. (Read by title.)

Energy Losses in Commercial Hammers. EDWIN MORRISON and ROBERT L. PETRY.

The Dynamics of Capillary Flow. EDWARD W. WASHBURN.

Diathermancy of Ice, Water, and Steam. S. L. BROWN.

The Effect of Cooling on a Cement Pier. ERNEST A. HODGSON.

The Use of the Differential Thermo-couple in Melting Point Determinations. O. H. GISH.

A Seasonal Breakage of the Mainsprings of Watches. S. R. WILLIAMS.

Transmission and Absorption of Sound by a Porous Material. PAUL E. SABINE.

Effect of Humidity on Sound Absorption. PAUL E. SABINE.

The Acoustical Double Resonator and Its Applications. F. R. WATSON.

Moving Pictures of Wave Motion. F. R. WATSON and A. G. ELDREDGE.

A Portable Sound Producer of Considerable Range as to Frequency and Intensity. E. A. ECKHARDT.

The Sound Field of a Parabolic Mirror. E. A. ECKHARDT.

Apparatus for Measuring Sound Intensity. J. C. KARCHER.

A Method of Measuring Phase Differences in a Sound Field. J. C. KARCHER.

An Acoustic Wave Filter. G. W. STEWART.

Minimum Sound Energy for Audition. F. W. KRANZ.

The Acoustics of Large Auditoriums. C. R. FOUNTAIN.

The Stability of the Atom as Related to Nuclear Composition. WILLIAM D. HARKINS.

The Separation of Isotopes. R. S. MULLIKEN and WILLIAM D. HARKINS.

The Abundance of Atomic Species as Related to Rutherford's Theory of Nuclear Structure. WILLIAM D. HARKINS.

The Variation of the Residual Ionization in Air with Pressure. K. MELVINA DOWNEY.

Influence of the Earth's Potential Gradient upon the Measurement of the Atmospheric Ionic Density by the Ebert Ion Counter. J. F. MACKELL.

The Dynamic Characteristics of Three-Electrode Vacuum Tubes. JOHN G. FRAYNE.

Secondary Electron Emission from Copper Surfaces. I. GARNETT BARBER.

Inelastic Collisions of Electrons in Vapors of Certain Compound Molecules. PAUL D. FOOTE and F. L. MOHLER.

The Effect of Angle of Incidence on the Reflection and Secondary Emission of Slow-Moving Electrons from Platinum. JOHN T. TATE.

A Comparison of the Thermionic and Photoelectric Work Function from Platinum. OTTO KOPPIUS.

The Photo-Electric Properties of the Audion Bulb Filament, Coated with Barium, Strontium and Calcium. THEODORE W. CASE. (Read by title.)

A Means of Distinguishing Between Intrinsic and Spurious Contact-Electromotive Forces. R. A. MILLIKAN.

Size and Ageing of Ions Produced in Air. HENRY A. ERIKSON.

The Formation of Negative Ions in Air. LEONARD B. LOEB.

The Structures of the Helium Atom and the Hydrogen Molecule. IRVING LANGMUIR.

The Cubic Shapes of Certain Ions, as Confirmed by X-Ray Crystal Analysis. WHEELER P. DAVEY.

The Crystal Structure of Two Rare Halogen Salts. WHEELER P. DAVEY and FRANCES G. WICK.

Multiple Valency in the Ionization by Alpha Rays. T. R. WILKINS.

Additional Experiments in the Nature of the Magnetic Molecule. S. J. BARNETT and L. J. H. BARNETT.

The Application of Interference Methods to Astronomical Measures. A. A. MICHELSON.

Some Peculiarities in Energy Distribution by Speculum Gratings. L. R. INGERSOLL.

The Coloration of Glass by Ultra-Violet Light. J. B. NATHANSON.

A Strained-Glass Elliptic Polarizer and Analyzer. A. DEFOREST PALMER.

A Determination of Young's Modulus and of the Coefficient of Simple Rigidity of Natural Hexagonal Crystals of Selenium. L. P. SIEG, and R. F. MILLER. (Read by title.)

The Blackening of a Photographic Plate as a Function of Intensity of Light and Time of Exposure. P. S. HELMICK.

The Intensity of Light Transmitted Through a Deep Slit. L. P. SIEG, and A. T. FANT.

The Relation of Optical Dispersion and Crystal Structure in Rock Salt and Sylvite. H. H. MARVIN.

Some Diagrams of Lines of Force of Moving Electric Poles. H. BATEMAN.

A High Frequency Resistance Standard. JOHN G. FRAYNE.

The Effect of a Superposed Constant Field Upon the Alternating Current Permeability and Energy Loss in Iron. ALVA W. SMITH.

Effect of Strong Electrostatic Fields on the Vaporization of Tungsten. A. G. WORTHING.

A Low-Voltage Cathode-Ray Oscillograph. J. B. JOHNSON.

A Theory of the Electrical Resistance of Metals. P. W. BRIDGMAN.

Tube Experiments, with the Cathode Region in a Traverse Magnetic Field. L. THOMPSON. (Read by title.)

Piezo-electric Activity of Rochelle Salt under Various Conditions. J. VALASEK.

An Experiment on Electromagnetic Induction and Relative Motion. W. F. G. SWANN.

Vertical Electrical Currents and the Relation Between Terrestrial Magnetism and Atmospheric Electricity. LOUIS A. BAUER.

The Eclipse Magnetic Systems of May 29, 1919. LOUIS A. BAUER.

Anhysteretic Curves of Iron-Carbon Alloys Made with a Braun Tube. C. W. WAGGONER and F. A. MOLBY.

Positive Ray Analysis of Magnesium. A. J. DEMPSTER.

Pressure Shifts in a Calcium Arc. HENRY G. GALE, and L. F. MILLER.

The Luminescence of Zinc Oxide Above the Red Heat. EDWARD L. NICHOLS (Read by title.)

Some Additional Measurements of Wave-Lengths in the Calcium Arc in Vacuo. GEORGE V. MCCAULEY.

Approximate Computations of X-Ray Absorption Frequencies. WILLIAM DUANE.

The Evidence Regarding the So-Called "J" Radiation in the Characteristic X-Ray Spectra of the Elements. F. K. RICHTMYER.

The Spectrum of Helium in the Extreme Ultra-Violet. HUGO FRICKE and THEODORE LYMAN.

Character of the Spectra Produced by High Potential Sparks in a Vacuum. EDNA CARTER.

The Absorption of Light by Mixtures of Inorganic Salts. E. F. GEORGE.

Intra-Red Spectra of Isotopes. F. W. LOOMIS.

The Absorption Spectra of Ortho-Cresolsulphonphthalein. W. R. ORNDORFF, R. C. GIBBS, M. SCOTT and S. D. JACKSON.

DAYTON C. MILLER,
Secretary.

THE RESISTANCE OF A COMPRESSIBLE FLUID AT HIGH VELOCITIES.

BY L. THOMPSON.

THE difficulties involved in an attempt to describe the motion of rigid bodies in viscous fluids by means of the equations of Hydrodynamics, are well known. Oseen[1] has introduced a system of equations which lead to results at considerable variance with those of classical hydrodynamics, particularly with reference to the essentially different character of the motion of the fluid in the rear, or wake, from that in front of the body, the former not being irrotational even in the limiting case of zero viscosity. In many instances the solution of the problem, with small viscosities, may be reduced to the determination of a potential function.

It is not likely that a complete description of resistance phenomena for velocities approximating that of sound, or higher, in compressible media, will be given by any other than a purely statistical investigation. This report concerns a plan which is being carried out in the case of small bodies (projectiles of different shapes), for a range of velocities obtainable with modern rifles, the object being the simultaneous determination of the total drag and at least two of the three principal factors or partial drags, together with their rates of change, as a function of the velocity and of the density. There is a considerable advantage in the use of small bodies, particularly in the evaluation of the pressure over the surface (which values give by integration, the partial drags, except that due to friction), since this can be accomplished by passing the trajectory through an interferometer field.

The experiments for the total drag are being made with projectiles of .4 inches diameter or less. The procedure is an improved form of an optical method described in an earlier paper.[2] The firing is done through a tube in

[1] C. W. Oseen, "Zur Theorie des Flussigkeitswiderstandes," Nova Acta R. Soc. Sc. Upsaliensis, Ser. IV., Vol. 4. Beitrage Zur Hydrodynamik, Ann. d. Phys., 41.

[2] L. T. E. Thompson, C. N. Hickman and N. Riffolt, "The Measurement of Small Time Intervals and Some Applications, Principally Ballistic," Proc. Nat. Acad. of Sciences, Vol. 6, No. 4.

which the density can be varied, and the observations are made on the time of passing of certain points in the trajectory, secured by the repeated interruption of a beam of light which crosses at these places, being controlled by a proper optical system to give images of a slit source. The beam is focused on a moving film. The shadow images of the projectile obtained, have a very sharp base line, from which the time measurements are made. The time calibration is produced on the record by means of light from a stationary slit, intermittently illuminated at regular intervals of twice the frequency of a freely vibrating control fork. From these observations the space time statistics are obtained with precision. Having $S(t)$ (an empirical relation, by fitting equation to data), the values of $v = S'(t)$ and v' are found and $R(v, \rho)$ or $kv'(S'(t), \rho)$.

Observations over 150 feet at normal air density will give a precision of at least one half per cent. in R (using .30 cal.), with the accuracy possible in the time and length measurements. By use of pressures as great as five or six atmospheres in the tube, and light projectiles (aluminum) of .30 or .22 cal., a distance of 20 to 25 feet is sufficient. The total work done, or kinetic energy change, is such that the velocity decrement is equivalent to that for a length of over 300. feet with heavy projectiles under normal circumstances. This permits better control of conditions for the set of experiments and greater accuracy of measurement. An additional advantage in the use of high density for the work with small projectiles is evident from the form of the expression for the resistance given by dimensional considerations: $R = \rho V^2 L^2 f(\mu/VL\rho, V/V_s)$, where μ is the viscosity, L is a length defining the scale and V_s the velocity of sound. From the values of f determined by experiment with the small bodies, the resistance for larger, similar bodies may be had, providing $\mu/VL\rho$, V/V_s are kept of the same value. Then for the small L, ρ should be large, and comparable velocities will be approximately equal.

The same apparatus can be used for the investigation of motion through solids, by cutting away enough of the solid in the line of flight to allow the beam of light to cross as before, or by the use of slabs of the solid, set up between the various sections of the beam. This is of importance in the ballistics of penetration and has application in plate and projectile testing. Either the resistance function, or simply the loss of kinetic energy on passing through one plate, can be found. The distance of observation need not be greater than one or two feet. This is desirable since the projectile might be deflected from the field by the plate, for long distances. Also the records show the manner in which the projectile is travelling.

KALAMAZOO COLLEGE.

THE THERMAL EXPANSION OF NICKEL, MONEL METAL, STELLITE AND STAINLESS STEEL.

BY WILMER SOUDER AND PETER HIDNERT.

THE increasing use of nickel and nickel alloy wire in spark plugs, of monel metal for high pressure steam valves, stems, seats, etc., of stellite for

surgical and household uses and of stainless steel for numerous purposes has created a demand for accurate data on the thermal expansion of these materials. Differential expansions between nickel and porcelain in spark plugs, and between monel metal and steel or brass in steam valves are important factors to be considered by manufacturers of these articles.

The apparatus used was the same as that described in Scientific Papers of the Bureau of Standards, No. 352.

Some of the results are presented in the following table.

TABLE.

Materials.	Average Coefficients of Expansion $\times 10^6$.		
	Room Temp. to 100° C.	Room Temp. to 300° C.	300° to 600° C.
10 samples of commercial nickel (94 to 99 per cent. Ni)	12.9 to 13.5	13.8 to 14.6	15.3 to 17.0
10 samples of monel metal (60 to 69 per cent. Ni)	13.7 " 14.5	14.9 " 15.2	16.6 " 18.4
5 samples of stellite (various grades)	11.0 " 15.6	12.4 " 16.7	14.7 " 18.0
1 sample of stainless steel (C 0.30, Si 0.11, Mn 0.18, S 0.011, P 0.020, Cr 13.10)	10.3	11.3	12.9

A more detailed report giving curves and tables of data is being prepared for later publication.

BUREAU OF STANDARDS,
WASHINGTON, D. C.,
November 1, 1920.

ENERGY LOSSES IN COMMERCIAL HAMMERS.

BY EDWIN MORRISON AND ROBERT L. PETRY.

IT is a well-known principle of mechanics that in case a moving object impinges against another object that the total momentum before impact is equal to the total momentum after impact. This law does not permit us to infer, however, that there are no energy losses in impacts. In fact the kinetic energy is less after impacts than before impacts of two impinging objects. It recently became of interest to study the relative values of energy losses from lack of perfect elasticity in different grades of commercial hammers, including railroad track hammers. To make these tests a hammer was substituted for one of the steel spheres in a common laboratory impact apparatus. Three grades of common mechanics' hammers secured from a hardware store have been tested with the following results for the energy losses: first grade 2.3 per cent., second grade 5.3 per cent., third grade 9.3 per cent. A similar hammer from the counter of a five and ten cent store showed a loss of 20 per cent. Railroad track hammers show an energy loss of from 2.3 per cent. to 5 per cent.

MICHIGAN AGRICULTURAL COLLEGE.

THE DYNAMICS OF CAPILLARY FLOW.

BY EDWARD W. WASHBURN.

THE rate at which a liquid penetrates a small cylindrical capillary of radius r is, according to Poiseuille's law,

$$\frac{dl}{dt} = \frac{Pr^2}{8\eta l}, \tag{1}$$

where P is the driving pressure, l the length of the column of liquid at the time t, and η the viscosity. For horizontal capillaries or for any capillary with a sufficiently small surface the integral of equation (1) reduces to

$$l^2 = \frac{r}{\eta}\frac{\cos\theta}{2}rt \tag{2}$$

for a liquid flowing under its own capillary pressure, r being the surface tension and θ the angle of contact.

The quantity, $(r/\eta)(1/2\cos\theta)$, measures the penetrating power of a liquid and may be called its *coefficient of penetrance* or its *penetrativity*.

Experiments with water, mercury and several organic liquids, using both vertical and horizontal glass capillaries of various sizes, verified completely the validity of the integral of equation (1). A dynamic method of measuring surface tension can be based upon equation (1). It is superior to the static method of capillary rise in that the result does not depend upon the radius of the capillary at a single point but upon its average radius.

If a porous body behaves as an assemblage of very small cylindrical capillaries, the volume, V, of liquid which will penetrate it in the time t, is given by

$$V = k\left(\frac{r}{\eta}t\right)^{1/2}. \tag{3}$$

In the light of this result some data obtained by Cude and Hulett on the rate of penetration of charcoal by water were examined and the degree of pene-

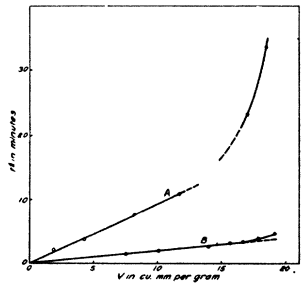

Fig. 1.

tration was in fact found to be proportional to the square root of the time, for the initial period of penetration (Fig. 1). Later the rate of penetration was much slower than required by equation (3). Whether this slower rate is due

to the previous complete filling of all except micropores or whether it is due to the slower filling of expanding pores or pockets could not be determined, although the former supposition seems more probable in this instance.

DEPARTMENT OF CERAMIC ENGINEERING,
UNIVERSITY OF ILLINOIS.

DIATHERMANCY OF ICE, WATER AND STEAM.

BY S. L. BROWN.

THE results of experiments by Tyndall, Magnus and others indicate that ice and water do not transmit but a small percentage of the incident radiant heat but these experimenters do not agree about the diathermancy of aqueous vapor.

The plan of the experiment to be described here was to measure the radiation transmitted by ice, water and steam as the temperature of the source of radiation is raised to 1000° C. The radiation from a tubular electric furnace was focused by a concave metallic mirror on a sensitive resistance element which was several feet away from the furnace. A plate of ice or a stream of water or steam was placed between the furnace and the focusing mirror and the percentage of the radiation absorbed by the intercepting screen was measured by the change in the electrical resistance of the element at the focus of the mirror. This method preserves the character of the incident, black-body radiation from the furnace since it is not changed by being sifted through glass or any other material before it reaches the substance under investigation as would be the case when the substance is enclosed in glass or any other more or less transparent material. For example, neither glass nor water are diathermanous to the shorter heat rays, and therefore, any measurements of the total radiation transmitted through water contained in glass would only indicate the transmission through the water of those rays that are not absorbed by either glass or water.

The results show that ice and water are decidedly athermanous to the total black-body radiation for temperatures of the radiating source up to 400° or 500° C. but may transmit 20 or 25 per cent. of the incident radiation when the temperature of the source is raised to 1000° C. Steam does not show any absorption whatever when the precaution is taken not to allow any condensation at the surface of the stream of steam by contact with the cooler air. Condensation on either side of the steam jet was prevented by passing it through an iron tube which was heated to a temperature higher than the temperature of the steam and allowing the radiation from the furnace to pass through the steam and across the tube through lateral openings in the heated tube. Any condensation of steam produced an absorption comparable with the absorption of water. The conclusion is that a jet of dry steam 1.5 millimeters thick certainly does not absorb as much as one per cent. of the total radiation for the temperature range of the radiating source from 500° C. to 1000° C.

Substance	Thickness.	Temperature of Radiating Source.	Per Cent. Transmitted.
Ice	3 mm.	500	1
"	"	600	3.5
"	"	700	6.5
"	"	800	9.5
"	"	900	13.5
"	"	1000	17.5
"	6 mm.	600	2
"	"	700	5
"	"	800	7.5
"	"	900	11.5
"	"	1000	15.5
"	60 mm.	700	2.5
"	"	800	5
"	"	900	8
"	"	1000	11
Water	.5 mm.	300	2.5
"	"	400	5
"	"	500	8
"	"	600	11
"	"	700	14
"	"	800	17.5
"	"	900	21.5
"	"	1000	25.5
Steam	1.5 mm.	500	100
"	"	1000	100

UNIVERSITY OF TEXAS.

THE EFFECT OF COOLING ON A CEMENT PIER.

BY ERNEST A. HODGSON.

THIS paper gives the results obtained at the Dominion Observatory, Ottawa, Canada, from experiments carried on for the past four years with an instrument known as the "Deformation Instrument," which was set up to investigate the rigidity of the earth but which was interfered with by the peculiar behavior of the cement pier on which it was mounted. The deformation instrument is an arrangement of horizontal pendulums in a very sensitive Zöllner suspension, which records photographically the movements of these pendulums. Its sensitivity is such that a tilt of .01 sec. or one inch in 300 miles records as about a millimeter on the record when the pendulums are given a period of 30 sec. If a small electric heater be stationed behind the pier upon which the instrument is mounted, and about 20 cm. from it, the whole will come to equilibrium after some days with the back face near the heater at about 69° F. and the front face at about 61° F. If now the heater be turned off for say 3 hours and then be turned on again, four phenomena appear in the records. First, after about an hour oscillations appear in the

record, indicating a periodic tilting which interfers with the period of the pendulum and hence has maxima and minima. (If the heater be left off several days equilibrium will finally be reached, but in the interval the oscillations will continue to show.) Second, on turning on the heater again the light spots indicate a tilting back in the opposite direction, *i.e.*, in the direction to be expected. After this drift has gone on about .01 sec. of arc it pauses. Third, the drift then continues after about ten minutes and maintains this return drift for about an hour at which time it has nearly returned to its old position. This drift after the pause is about 6 mm. varying of course in different experiments. This indicates a tilt of say .065 sec. of arc. Fourth, the drift reverses in direction although the heating is maintained and this reverse goes on until the tilt is greater than it was at the end of the whole period of cooling before the heater had been turned on again. This reverse tilt is of the order of .22 sec. After this the pier top tilts back in the direction one would have expected on heating, but it takes about a day to reach the former position of equilibrium. If the whole experiment is tried in the reverse direction *i.e.*, the whole in equilibrium with the heater off, the heater then turned on for about three hours and then turned off again, the oscillations do not appear. If the heater be left on until equilibrium is again reached the entire curve is always smooth. It is suspected that the anomalous reverses in direction may sometimes occur but this point is not certain. Certainly there are no oscillations in any case in the heating curves. Various possible applications of these phenomena are suggested. Among these emphasis is laid on the hypothesis, suggested by the writer, that a somewhat similar phenomenon may be the source of the micros which obscure seismological records during the winter months. The paper gives full details of the experiments, including a full description of the deformation instrument itself. It will appear shortly as a publication of the Dominion Observatory.

DOMINION OBSERVATORY,
OTTAWA, CANADA,
December 25, 1920.

THE USE OF THE DIFFERENTIAL THERMO-COUPLE IN MELTING POINT DETERMINATIONS.

BY O. H. GISH.

WHEN the latent heat of fusion is small or the melting process consists of several transformations as is the case with many alloys, ordinary cooling curve methods are inadequate for measurements of the melting point, or a study of the melting process.

Though used to advantage in detecting transformations in solids the differential thermo-couple seems never to have been adapted to such use where transformations occur in the presence of a liquid phase.

The item of chief importance in this method is the design of crucible. A convenient form was made as follows:

The upper half of a cylinder of graphite was turned out in the usual shape for a crucible except that a narrow truncated cone was left along the axis and extending about two thirds way from the bottom to the top. A hole from the bottom of the cylinder extending up through the solid portion and nearly to the tip of the small truncated cone, referred to above, was made to admit the sheath and the thermo-couples it contained. A lid was also provided for the crucible.

With this device a Leeds and Northrup temperature indicator potentiometer was used for the temperature measurements and a low resistance galvanometer was used in connection with the difference couple.

When the E.M.F. of the differential couple produced too great a deflection on the galvanometer the deflection could be reduced by adjusting a counter E.M.F. which with a high resistance in series was applied across the posts of the galvanometer.

This method was found to possess the advantage that melting points could be found without taking a series of readings and plotting curves but simply by reading the potentiometer at the instant the galvanometer in the differential thermo-couple circuit showed a marked disturbance.

Determinations made with this relatively inexpensive apparatus showed a maximum deviation at 800° C. of $\pm$ 2° C.

WESTINGHOUSE RESEARCH LABORATORY.

A SEASONAL BREAKAGE OF THE MAINSPRINGS OF WATCHES.

BY S. R. WILLIAMS.

IT is a very common belief among jewelers that after thunder showers they must be prepared to replace an unusual number of mainsprings. This they ascribe to the effect of electricity in lightning. If any truth is to be found in such a belief a study of the records which jewelers keep of their repairs should show a seasonal breakage of mainsprings. Such a study was made and a very pronounced effect was found. The seasonal breakage is not, however, due to electricity or magnetism or such causes but due to moisture which starts rust in minute spots either on the surface of the spring or in tiny cracks causing the skin effect of the steel to be weakened and the spring lets go. Oil on the surface of the springs prevents breakage when the springs are placed in a moist atmosphere and leads to a well-established principle that an ounce of preventive medicine is worth a pound of cure.

OBERLIN COLLEGE,
OBERLIN, OHIO.

TRANSMISSION AND ABSORPTION OF SOUND BY A POROUS MATERIAL.

BY PAUL E. SABINE.

USING the method of reverberation, simultaneous measurements of transmission and absorption of sound by different thicknesses of hair felt have been made, covering the entire range of frequencies of the ordinary musical tones.

These measurements indicated that for all frequencies, the logarithm of the reduction in the intensity of the transmitted sound is proportional to the thickness of the material through which it passes. The proportionality factor for the material tested is a linear function of approximately the fourth root of the frequency. An apparent exception was noted in the case of the highest frequency used 4,096 p.p.s. for which the reduction was somewhat less than that called for by this rule. The relation of the incident and the transmitted intensities may be expressed by an equation of the form

$$I_t = AI_0e^{-md},$$

in which A for any frequency is a constant whose value is determined by the absorption coefficient of the material for that frequency and d is the thickness. The value of m is given by an equation of the form

$$m = m_0(f/f_0)^p,$$

in which the constant m_0 and p are probably different for different materials depending on the closeness of the felting.

The values of the absorption coefficient were found to increase with increasing thickness of absorbing material but they approach limiting values which are reached at smaller thicknesses for the higher frequencies. An auxiliary experiment indicated that the change of absorption with change in thickness follows the same law as the reduction of the energy of flow of an air stream through the material. The dissipation of energy of flow through the material at constant pressure approaches a limiting value as the number of layers of the material is increased.

WALLACE CLEMENT SABINE LABORATORY,
RIVERBANK, GENEVA, ILLINOIS.

EFFECT OF HUMIDITY ON SOUND ABSORPTION BY PLASTER WALLS.

BY PAUL E. SABINE.

THE absorption of sound by a massive rigid wall has been shown to be due in large part to the dissipation of energy in the pores of the reflecting surface. Absorption due to this cause increases with the frequency of the sound. Walls of ordinary plaster have been found to show slight increase in absorption with aging due presumably to increased porosity. A marked decrease in the absorption by the walls for sounds of high frequency with large increases of humidity in the room, has been observed. Thus walls of hard gypsum plaster were observed to show a gradual decrease in absorption coefficient amounting to twenty five per cent. of the original coefficient for the tone 4,096 when the relative humidity in the room was increased from 45 per cent. to 85 per cent. Weighings of a small sample of the plaster showed that in a humid atmosphere an amount of water equal to one half of one per cent. of the weight of the sample was taken up. The closing of the minute pores in this way will account for the decreased sound absorption since the latter decreases with decreasing size of the pores.

WALLACE CLEMENT SABINE LABORATORY,
RIVERBANK, GENEVA, ILLINOIS.

THE ACOUSTICAL DOUBLE RESONATOR AND ITS APPLICATIONS.

BY F. R. WATSON.

DOUBLE resonators of suitable dimensions are much more sensitive in amplifying sound than single resonators.[1] A double resonator consisting of two chambers of unequal volume connected by a short narrow tube has been used by the writer in measuring sound. A Rayleigh disc suspended in the connecting tube allows a quantitative measurement of the energy. By using a delicate quartz suspension and a proper dimensioning of parts, an instrument may be constructed that has the same order of sensitivity as the ear.

Another modification of a double resonator has resulted in an acoustic galvanometer. A telephone receiver is screwed to the open end of the resonator mentioned in the previous description and generates sound when the telephone plate is agitated by an electric current in the receiver. A Rayleigh disc, as before, gives quantitative measurements. Calibration of the instrument shows it will give a response for alternating currents of the order 10^{-8} amperes.

An acoustic relay has also been developed. This consists of two chambers of equal volume with a short connecting tube containing a Rayleigh disc. Each chamber has a telephone receiver screwed to the outer end. If an alternating current of selected pitch is passed through the receivers, the sound generated is amplified by the double resonator and causes the Rayleigh disc to rotate slightly. By suitably mounting the disc with a projecting pin, a record of the telephone action may be obtained either mechanically by an inked trace or electrically by closing an auxiliary circuit.

UNIVERSITY OF ILLINOIS.

A PORTABLE SOUND PRODUCER OF CONSIDERABLE RANGE AS TO FREQUENCY AND INTENSITY.

BY E. A. ECKHARDT.

A SOUND producer which is quite portable, and which has a considerable range both as to frequency and intensity, has been devised. It consists of an electro mechanical output element, the diaphragm of which is cupped in a manner which serves to suppress partial vibrations. The alternating current generator is of the triode type. A wiring diagram is shown in the paper. Two tubes are used, the one serving as an oscillator and the other as an amplifier. The adjustments of the second tube have slight effect on the frequency, but control the amplitude of the alternating current over relatively wide limits. Oscillograms of the current generator and of the diaphragm motion are shown. Constancy of frequency and intensity is discussed.

BUREAU OF STANDARDS,
WASHINGTON, D. C.,
December, 1920.

[1] Lord Rayleigh, Th. of Sound, Vol. 2, sec. 253b.

MOVING PICTURES OF WAVE MOTION.

BY F. R. WATSON AND A. G. ELDREDGE.

MOVING pictures of capillary waves on water have been secured showing propagation, interference and reflection of waves. The waves were generated by the apparatus used earlier by the writer.[1] A stream of compressed air is interrupted by a circle of holes in a rotating disc so that puffs of air strike the water surface and generate the waves. To make these visible, light from an arc passes through a second series of holes in the disc and is reflected upward through the glass bottom of the water tank so as to cast a shadow of the waves on a frosted glass. The camera photographs this moving shadow. It is the intention to take further photographs of waves, also of the action of mechanical devices to show wave motion.

UNIVERSITY OF ILLINOIS.

THE SOUND FIELD OF A PARABOLIC MIRROR.

BY E. A. ECKHARDT.

MEASUREMENTS of intensity and phase distribution in the field of a parabolic mirror are described. The mirror investigated was approximately nine (9) feet in diameter, and three (3) feet in focal length. Curves for the following intensity and phase distributions are shown.

1. Intensity distribution across the face of the paraboloid along a line through the focus, the mirror registering on the distant source of sound.

2. Intensity change at principal focus as the paraboloid axis is swept past the distant source of sound.

3. Intensity change at each of a pair of receivers symmetrically disposed relative to the principal focus as paraboloid axis is swept past the distant source of sound.

4. A series of curves as in 2, the paraboloid being progressively reduced in size from one curve to the next.

5. Phase distribution across face of paraboloid along a line through the focus, the mirror registering on the distant source of sound.

6. Phase change at principal focus as paraboloid axis is swept past distant source of sound.

7. Phase difference between a pair of receivers symmetrically disposed relative to focus as paraboloid axis is swept past the distant source of sound.

It is believed that the data obtained will supply a rational basis for the design of listening equipment to be used in conjunction with the paraboloid.

BUREAU OF STANDARDS,
WASHINGTON, D. C.,
December, 1920.

[1] PHYSICAL REVIEW, Vol. 7, p. 226, 1916.

APPARATUS FOR MEASURING SOUND INTENSITY.

BY J. C. KARCHER.

MOST apparatus for measuring sound intensity at any frequency, such as the Rayleigh disc or the Webster phonometer, does not permit of ready change from one frequency to another over a wide range. The apparatus here described is an extension of that devised by Prof. G. W. Pierce in which a telephone receiver is the receiving element, and a crystal detector-galvanometer circuit is the essential indicating element. In order to increase the intensity range of the instrument two stages of triode amplification are introduced, one or both of which may be used according to the requirements of the problem.

The circuits and properties of the apparatus are discussed, and a wiring diagram is given. Calibration curves for a number of frequencies and a number of crystal rectifiers are shown.

BUREAU OF STANDARDS,
WASHINGTON, D. C.,
December, 1920.

A METHOD OF MEASURING PHASE DIFFERENCES IN A SOUND FIELD.

BY J. C. KARCHER.

A TELEPHONE receiver becomes a feeble alternating current generator when its diaphragm is acted upon by a continuous sound wave. If the sound is constant as to frequency and intensity the alternating current E.M.F.'s generated will be similarly constant. If a second receiver be placed in the same sound field the E.M.F. generated in it may differ slightly in amplitude and considerably in phase. If the two receivers be connected in series the joint circuit will have an impressed E.M.F. which is the vector sum of its components.

The squares of this vector sum and of the component E.M.F.'s are indicated by the galvanometer readings of the sound intensity measuring device described in another paper. The three sides of the vector triangle are thus obtained and the angle between the components, the phase angle is determined graphically. A few results obtained by this method are discussed.

BUREAU OF STANDARDS,
WASHINGTON, D. C.,
December, 1920.

AN ACOUSTIC WAVE FILTER.

BY G. W. STEWART.

AN electric wave filter is well known (vide Chapter XVI., Electric Oscillations and Electric Waves, Pierce, 1920). It consists of a series of sections placed in a transmission line, each section containing an impedance in series in the line and an impedance in shunt across the line, these alternating

in sequence. These impedances can be so selected as to transmit without serious attentuation a group of sinusoidal currents between two assigned frequency limits and yet approximately extinguish the currents of neighboring frequencies.

Herewith is presented an acoustic wave filter whose theory is found to be of the same form as that of an electric wave filter that attenuates all frequencies above an assigned value. The formula for such an electric filter is,

$$(2\pi f)^2 = \frac{4}{L_1 C_2},$$

where f is the assigned frequency, L_1 is the inductance in series in the line and C_2 the capacity in shunt.

An analogous acoustic wave filter is found to consist of a cylindrical tube through which the transmission occurs, having a series of side openings equally spaced along the axis, with each opening surrounded by an enclosed volume whose dimensions are large compared to that of the opening. In the actual filters, the single aperture may be really several apertures with centers lying in the same cross-section. In the filter the dimensions are small in comparison with the wave-length for which the transmission is to be extinguished. The attenuation is not caused by dissipation but by the reactions between the sections. The formula for this acoustic wave filter can be shown to be:

$$(2\pi f)^2 = \frac{4 S_1 a^2}{l V},$$

where S_1 is the area of the cylindrical tube, a is the velocity of sound in the air, which is the medium used, l is the distance between the apertures in the tube and V is the volume of air in each branch.

The theory of the acoustic wave filter is much more approximate than that in the electrical case, and the interest rests chiefly in the practical success of the acoustic filter. As illustrative of the performance of the filters, the following data are given:

Filter.	Area of Each Aperture.	Number of Sections.	S	l	V	Computed f.	Observed f.
A....	.236(2)	3	.185 cm.^{2}	2.66 cm.	21.4 cm.^{3}	654	650 approximately
B....	.236(4)	3	.185 cm.^{2}	5.0 cm.	42.7 cm.^{3}	323	350 approximately

In each of these filters the transmission between the cut-off frequency and 3,000 d.v. was very small, certainly less than 10^{-7}. This means that the transmitted intensity with a moderately loud incident intensity is inaudible.

In filter A, the transmission from 90 to 500 d.v. was approximately 21 per cent.; in B from 90 to 500 d.v., it was approximately 16 per cent.

That the attenuation is due to the reaction among the sections and is not absorption is indicated experimentally by the fact that the transmission of the

desired frequencies is greater for filters of three sections than for filters of one section but otherwise of the same dimensions.

PHYSICAL LABORATORY,
STATE UNIVERSITY OF IOWA.

MINIMUM SOUND ENERGY FOR AUDITION.

BY F. W. KRANZ.

THERE have been experiments made by several different observers to determine the minimum sound energy required for audition, and the variation of the sensitivity of the ear with frequency. The results obtained vary over a considerable range, the values given by Wien[1] showing a much greater sensitivity of the ear and a much greater variation of this sensitivity with frequency than those obtained by Rayleigh,[2] Zwaardemaker and Quix,[3] and others.

A new determination of the ear sensitivity seemed desirable and this was undertaken with a thermo-phone as the source of sound, this being a thin metal strip heated by an electric current. The theory of the thermo-phone has been worked out by Arnold and Crandall[4] and a quantitative expression given for the sound energy produced in terms of the electrical input and the constants of the metal strip. In the present experiment, the thermo-phone element was placed in a small telephone receiver case and held tightly to the ear. The other ear was closed by a dummy head receiver and the experiment was conducted in a padded room, so that external noises were eliminated entirely. A second person opened and closed the electric circuit with a knife switch, and the input was reduced in small steps until the observer became uncertain in his judgments as to when the switch was opened and closed, these judgments being indicated by a movement of a finger. The alternating input was measured with a thermocouple and a micro-ammeter. A direct current of one ampere was used in the thermo-phone which was of platinum, 0.000216 cm. thick. Six frequencies were used, covering the range from 128 to 4096 p.p.s. in intervals of an octave, a vacuum tube oscillator furnishing the alternating currents from which the harmonics were eliminated by means of electrical filters.

The results showed a wide difference in sensitivity for different ears, observations being made on eight ears. Some of the ears showed as great a variation of sensitivity with frequency as is indicated by Wien's data, the energy necessary for audition at 128 p.p.s. being 100,000 times that required at 2048 p.p.s. The smallest rate of energy flow necessary in any observation was about 10,000 times the minimum found by Wien, and was 2.2×10^{-8} ergs per square centimeter per second, the frequency being 2048 p.p.s. The corresponding particle displacement is 0.025 $\mu\mu$.

WALLACE CLEMENT SABINE LABORATORY,
RIVERBANK, GENEVA, ILLINOIS.

[1] Archiv. für die gesammte Physiologie, V. 97, p. 1–57, 1903.
[2] Phil. Mag., V. 38, p. 370, 1894.
[3] Archiv. für Anat. und Physiol., Supplement, 1902.
[4] PHYS. REV., V. 10, p. 22–38, 1917.

The Acoustics of Large Auditoriums.

By C. R. Fountain.

An account of the acoustics of the New City Auditorium of Macon, Georgia, is given. This is a temporary structure, except for the steel framework, which had been boarded up with rough boards, with cracks in many places. Its dimensions are roughly $200' \times 130' \times 60'$ high. Its volume = 47,000 cu. meters.

Attempts had been made to improve the acoustics by hanging large plush curtains on the stage, muslin on the rear wall and wires stretched through the auditorium.

Under these conditions ordinary speaking tones could not be heard even faintly in the center of the building. I expected trouble with reverberation, but found none. Calculation by Sabine's formula for wooden wall, making allowance for open window area represented by cracks, etc., the reverberation came out 13 seconds when empty and 3.5 seconds with an audience of 2,500 on the floor.

This discrepancy may be accounted for in several ways:

1. The boards were thin, the surfaces rough, and cracks were plainly visible in many places.

2. The slope of the roof was such that the reflected waves would concentrate the sound energy at the eaves which were open.

3. The plush curtains on the stage, and the large volume behind them would prevent energy radiated in that direction from ever getting out.

4. The great volume of the auditorium made it impossible to saturate it with an intensity 10^6 times the minimum for audibility.

My problem not being one of reducing reverberation, I prepared to get as much energy as possible directed toward the audience with as few reflections as possible.

An inner stage, $40' \times 20' \times 10'$, was constructed of plaster on wood lath.

The result was an almost uniform distribution of energy throughout the auditorium for the sounding body at any point on the stage except the extreme front corners. The intensity was such that a pin dropped on the stage could be heard at any point in the building.

Very large sustained tones gave some reverberation, but hardly as much as is desirable.

The chief points to be considered are these:

1. Walls with cracks in them probably have a much larger total absorption than would be obtained by adding the area of the cracks to the open window value of the boards themselves.

2. Open windows or openings at certain places may increase the absorption much more than their total area.

3. Reflected waves which arrive at a point after most of the direct radiation has gone by may not interfere very much with good hearing, even though they

operate to increase the total reverberation for intense tones to a point that would be very bad in a smaller auditorium.

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THE STABILITY OF THE ATOM AS RELATED TO NUCLEAR COMPOSITION.

BY WILLIAM D. HARKINS.

IN light atom nuclei the ratio $\frac{\text{total number of negative nuclear electrons}}{\text{total number of positive electrons}}$ is equal to 0.5 for most of the atoms of even atomic number, and only very slightly greater than 0.5 when the atomic number is odd. Since atoms of even atomic number are in general very much more abundant than those of odd atomic number, it may be assumed that the nuclei of the former are more stable, and that, if the above ratio is represented by N/P, then the value of this ratio requisite for the highest stability for a light atom nucleus is 0.5,—that is when one negative electron on the average binds two positive electrons. The most abundant light atoms are those of C, O, Mg^{24}, Si^{28}, S^{32}, and Ca, and the value of N/P in the nuclei of all of these atoms is 0.5.

Of the heavier atoms Fe^{56} seems from present evidence to be by far the most abundant. As the positive charge on the nucleus ($P - N = M$) increases, the relative number of negative electrons (or the value of N/P) necessary to give the maximum stability also increases, and rises to 0.536 in the extremely abundant Fe^{56}, and finally to 0.614 in uranium. It may be assumed that when the nuclear charge n is high, there as a large self repulsion in the nucleus. Corresponding to this no atom of nuclear charge higher than 28 is at all abundant. The effect of the high positive net charge (n) may be partly counteracted by an increase in the value of N/P. However if the value of N/P becomes abnormally high, the atom becomes unstable with respect to the emission of negative particles, so negative electrons,—beta particles,—are shot out. If N/P becomes abnormally low, then positive (alpha) particles are emitted. The values of $(N/P) - 0.5$ which give the highest stability, give, when plotted against either P or n, an hyperbola.

UNIVERSITY OF CHICAGO.

THE SEPARATION OF ISOTOPES.

BY R. S. MULLIKEN AND W. D. HARKINS.

EARLIER work in this laboratory has resulted in the partial separation of the element chlorine into isotopes, and this work is now being continued by Mr. Hayes. It is the purpose of this paper to consider the relations involved when the separation is carried on by diffusion through a porous wall and by vaporization into a vacuum. Since the principles of the latter method

are probably somewhat simpler on the whole, the treatment given will refer to this method, though the same formulæ are found to apply to a considerable extent to the diffusion. The general formulæ for the latter method have already been worked out by Rayleigh.

The rate of vaporization of a liquid into a vacuum is given by the equation of Hertz

$$N \text{ (molecules per cm.}^2 \text{ per sec.)} = \frac{p}{\sqrt{2\pi mRT}},$$

which has been tested by Knudser with mercury, and by Langmuir. The relative rate of evaporation of two isotopes from a mixture is therefore

$$\frac{R_h}{R_l} = \frac{h}{l}\sqrt{\frac{m_l}{m_h}} = K\frac{h}{l},$$

provided the vapor pressures of the two isotopes when separate, are equal, which seems now to be moderately well established Here h and l are the initial molecular percentages of heavy and light isotope, and m_h and m_l are the respective molecular weights. The composition of the first portion of the *condensate* can be shown to be given by

$$\Delta l = l_c - l = \frac{hl}{l + \frac{100K}{1-K}} = 0.01\, hl(1-K) \text{ (nearly)} - \frac{.01hl(m_h = m_l)}{2m_h}$$

nearly if $(m_h - m_l)/m_h$ is small. The atomic weight decrease is approximately

$$-\Delta m = \frac{.00005(m_h - m_l)^2 hl}{m_h}.$$

If a fraction C of the initial quantity of material is evaporated, the above values of Δl and Δm hold for the condensate if multiplied by

$$-\frac{(1-C)}{C}\log_e(1-C).$$

For the residue

$$\Delta h = -\frac{hl(1-K)}{hk+l}\log_e(1-C)$$

holds if Δh is small. Approximately

$$\Delta h = -\frac{0.0115(m_h - m_1)h_0 l_0 \log_{10}(1-C)}{m_h}$$

and

$$\Delta m = -\frac{0.000115(m_h - m_1)h_0 l_0 \log(1-C)}{m_h}.$$

The more general relations will be treated in the final paper.

UNIVERSITY OF CHICAGO.

THE ABUNDANCE OF ATOMIC SPECIES AS RELATED TO RUTHERFORD'S THEORY OF NUCLEAR STRUCTURE.

BY WILLIAM D. HARKINS.

EARLIER papers have given conclusive evidence that the abundance of the elements in the meteorites, and also in the surface of the earth, is a periodic function of the atomic number, with two elements in a period. Periods of this magnitude do not occur in the properties related to the number and arrangement of the outer or planetary electrons, but they do appear in the atomic weights, which makes it evident that the periodicity in question is dependent upon the composition and structure of the nuclei of the respective atoms. There are a number of facts which cannot be summarized here, which indicate that the relative abundance of the different atomic species is dependent to a considerable extent upon the stability of the respective nuclei, and also upon the stability of the electron aggregates from which such nuclei are built.

Since the radioactive atoms in their disintegration emit alpha particles of mass 4 (and charge 2+), and give off no other particles of appreciable mass, so far as is now known, it is a natural assumption that these heavy atoms, and possibly the lighter atoms as well, have nuclei which are built up largely from alpha particles. However, Rutherford, from the results of experimental work on the disintegration of light atoms, comes to the conclusion that he has driven out particles of mass 3 and charge 2 from their nuclei, and on this basis develops the hypothesis that these units of mass 3 are of much more importance than the units of mass 4 in the building of light atoms, though he still considers that the *alpha particles of mass* 4 *are of more importance in the building of heavy nuclei.*

In this connection it is of interest to take note of the following facts concerning the numerical relations involved: (1) Aston has now investigated the isotopes of 16 elements other than hydrogen, and it may be noted that in 9 of these the most abundant isotope has an atomic weight divisible by 4, while in only two is it divisible by 3. More striking than this is the fact that no such atomic weight is divisible by 3 except when it is also divisible by 4. (2) The analyses of 318 iron and 125 stone meteorites show that there are 7 elements present in appreciable quantities which have atomic weights divisible by 4 (but not by 3), and these 7 elements make up 87 per cent. of all of the atoms in these meteorites. Compared with this the atoms which have atomic weights divisible by 3, but not divisible by 4, make a poor showing, since they are represented by only 3 elements with a percentage of only 0.77 per cent. Thus the atoms of the type $4n$, where n is a whole number, are 113 times as plentiful as the atoms of atomic weight $3n$. (3) While the similar ratio for the surface of the earth is not quite so striking, it shows the presence of about 13 atoms of the type $4n$ to 1 of the type $3n$, or 72 per cent. of all of the atoms are of the former, and only 5.65 per cent. of the latter type. It has already been shown by the writer that the data on the meteorites are the more significant.

The extremely great predominance of atoms of the type $4n$ is shown by the

fact that in the meteorites 91.7 per cent. of the atoms have atomic weights equal to $4n$, only 1.26 per cent. equal to $4n + 1$, only 0.77 per cent. equal to $4n + 2$, only 1.46 per cent. equal to $4n + 3$, and while it is true that 5.90 per cent. have atomic weights equal to $3n$, the apparent second place in order of abundance is due to the fact that 5.14 per cent. of this amount is due to an atomic species which belongs also to the $4n$ type, so only 0.76 per cent. can be with certainty attributed to the $3n$ type.

In connection with the above data it may be remarked that a 4 is always equal to a 3 plus a 1, and also that when violent means are used to disintegrate chemical compounds atom groups are often driven off as molecules which have a different form of union than exists in the parent molecule. For example anhydrous oxalic acid contains no HOH group in its molecule, but nevertheless it gives water when it is heated.

The conclusion which the writer draws from the above facts is that while the group of mass 3 is probably of considerable importance in the building of atom nuclei, there is at present no sufficient basis for the abandonment of the theory that light nuclei (atomic numbers 2 to 28) are built up largely from alpha particles.

It should be noted that the isotope of helium of the nuclear formula $(\eta_3{}^+\beta)^{++}$, where η is the positive, and β, the negative electron, as discovered by Rutherford, is an *altogether new* type of nucleus, since in it the ratio of the number of negative (N) to positive (P) electrons is only $\frac{1}{3}$, while in *no known atom* which has more than a transitory existence, *has this ratio a value less than* $\frac{1}{2}$.

UNIVERSITY OF CHICAGO.

THE VARIATION OF THE RESIDUAL IONIZATION IN AIR WITH PRESSURE.

BY K. MELVINA DOWNEY.

THE present investigation is a continuation of a previous experiment in which a linear relation was obtained between the residual ionization and the pressure when the latter was varied over a range of twenty atmospheres in a sphere one foot in diameter. With the same apparatus, the ionization has been found to increase up to approximately 46.0 atmospheres according to a linear relation, the slope for which becomes somewhat lower at about 27.0 atmospheres. However, a constant value of the ionization was obtained from 46.0 to 56.7 atmospheres (the highest pressure for which a reading was recorded).

If the residual ionization were due to the direct action of a penetrating radiation, it would presumably increase at least at a linear rate. The attainment of an upper limit suggests an ionization arising from an emission from the walls of the vessel, this emission being possibly stimulated by the external radiation, and having a range at least as great as 14 meters at atmospheric pressure.

In this work very careful tests have been made for saturation voltage at the

highest pressures. The existence of a saturation voltage was also confirmed by experiments performed under the same conditions with lead-shielded radium bromide placed eight feet from the ionization vessel. In this case, the ionization, initially much larger, was found to increase over the entire range of pressure, but the slope of the ionization-pressure curve was found to change considerably at the high pressures.

It is of interest to note that the increase per atmosphere of the number of pairs of ions produced per c.c. per second is approximately 1.40 for a range from zero to twenty seven atmospheres, while from 27.0 to 46.0 atmospheres it is as low as 0.75. The increase per atmosphere, unlike the total ionization for one atmosphere, is largely free from any alpha radiation or soft beta radiation from the walls of the vessel, since such radiation is completely absorbed at the lower pressures. While it is impossible to discuss the significance of these low values in an abstract, it is of interest to observe that they are lower than the value 2.6 ions per c.c. per second obtained by McLennan for the total ionization at one atmosphere in a vessel of ice situated over Lake Ontario. They are, moreover, about the same as the value deduced by Gockel for the difference between the rate of production of ions one meter above a water surface and two meters below respectively, and attributed by him to the effect of a true penetrating radiation.

DEPARTMENT OF PHYSICS,
UNIVERSITY OF MINNESOTA.

INFLUENCE OF THE EARTH'S POTENTIAL GRADIENT UPON THE MEASUREMENT OF THE ATMOSPHERIC IONIC DENSITY BY THE EBERT ION COUNTER.

BY J. F. MACKELL.

IT has been pointed out by Prof. W. F. G. Swann[1] that measurements of ionic density made with the Ebert Ion Counter are subject to error owing to the influence of the charge which is induced on the top of the instrument by the atmospheric potential gradient. It appears that, for the normal sign of the potential gradient, the measured values of the negative ionic densities would be too low while those of the positive ionic densities would be unaltered. According to Swann, the error in the negative ionic density should amount to as much as 26 per cent. for a potential gradient of 70 volts per meter, in the case of an instrument which he examined. In view of some discussion as to the magnitude of the effect when the instrument is shielded with the cap with which modern instruments are provided, experiments have been undertaken to test the effects for this case.

Two similar ion counters were set up with their central systems connected to the respective pairs of quadrants of an electrometer whose outer case was raised to a potential of about 200 volts while the needle was kept at 100 volts. When both ion counters functioned, the effects on the electrometer tended to

[1] Terr. Mag. and Atmos. Elec., Vol. 19, p. 205, 1914.

compensate. The alteration of the effect produced by shielding one of the ion counters with a large earth connected hemispherical dome of wire netting could then be investigated. The effect of one of the ion counters alone could be obtained by disconnecting the other; and, in this way, the effect of the potential gradient could be investigated.

The results are summarized in the table herewith, which represents a large number of observations for the ranges of potential gradient given. N_+ and N_- refer to the measured numbers per c.c. of the positive and negative ions, and ΔN_+ and ΔN_- to the variations of these quantities caused by the potential gradient.

It will be seen that the results are in striking accord with the theory, the error in N_+ being practically negligible while that in N_- is very considerable.

Effect of Potential-Gradient on Measurement of Ionic Content.

Potent. Grad. Volts/Meter.	N_-	ΔN_-	$\left(\frac{\Delta N_-}{N_-}\right)\times 100$	N_+	ΔN_+	$\left(\frac{\Delta N_+}{N_+}\right)\times 100$	$\frac{N_+}{N_-}$	$\frac{(N_+ + \Delta N_+)}{(N_- + \Delta N_-)}$
			%					
30– 39	725	151	21	1,162	−4	0.4	1.63	1.34
40– 49	701	156	23					
50– 59	655	164	24	1,143	4	0.4	1.67	1.34
60– 69	710	174	25					
70– 79	679	193	28	1,145	0	0.0	1.63	1.28
80– 89	713	212	29					
90– 99	704	228	32	1,173	22	2.0	1.64	1.25
100–109	725	250	35					
110–120	713	257	36	1,156	0	0.0	1.61	1.20

DEPARTMENT OF PHYSICS,
UNIVERSITY OF MINNESOTA.

THE DYNAMIC CHARACTERISTICS OF THREE ELECTRODE VACUUM TUBES.

BY JOHN G. FRAYNE.

IT is an experimental fact that in the case of continuous currents the following relation holds between the plate current and the grid and plate potentials.

$$I_b = F(E_b + kE_c),$$

the b subscripts referring to the plate and the c subscript referring to the grid.

Now in the case of alternating currents and potentials if we postulate that at any instant the following relations hold.

$$I_b' = F(E_b' + kE_c'),$$

where the primes refer to the instantaneous values of current and potentials then the static and dynamic characteristics are really one and the same thing, it being borne in mind that now we are dealing with alternating current phenomena, and that the dynamic characteristic in consequence will need a different interpretation than that derived from direct current measurements. Unless the emission of electrons from the filament is in some way affected by the rapidly changing grid potential (if we are dealing with frequencies of the order of a million or more), and then we might expect the omission to depend on the previous history of the currents and potentials, the current at any instant will only be dependent on the instantaneous plate and grid potentials.

Van der Bijl has worked out an expression for the dynamic characteristic in the case when a pure sine wave is impressed between the grid and filament, and a resistance is placed between the plate and the plate battery. Assuming the parabolic current-potential relation, we have

$$I_b - A(E - RI_b + kE_c + ke \cos pt)^2.$$

In this case $E - RI_b$ is the instantaneous plate potential and $k(E_c + e \cos pt)$ is the instantaneous grid potential. Solving this for I, there results a series in ascending powers of $\cos pt$. As the series converges rapidly, only a few terms need be taken and the different powers of $\cos pt$ may be transformed into circular functions of multiples of pt. This enables us to write down the plate current in terms of its fundamental and harmonic components.

Using platinised quartz fibers as resistances the author has measured these different harmonics and found that they agree in general with the theoretical values. This result shows that the assumption that static and dynamic equations are identical must be true. Since the parabolic relation is only approximate it cannot be expected that the higher order of harmonics will approximate closely to the theoretical values, but the general behavior under different conditions can be predicted. It may be remarked here that even when operating on the portion of the characteristic where the harmonics have the greatest amplitude, below the third or fourth they are negligible compared with the fundamental. Measurements of these harmonics have been made, for different positions on the $E_b - I_b$, and the $E_c - I_b$ curves, and for different amplitudes of input potential and for different values of R in the plate circuit.

If the resistance be replaced by an inductance, the resulting value of I_b is not so easily determined, as a differential equation of considerable difficulty is encountered.

The characteristic equation now is

$$I_b = A\left(E_b + kE_c + ke \cos pt - L\frac{dI_b}{dt}\right)^2.$$

By writing I_b as the real part of the expression

$$a_0 + a_1 e^{ipt} + a_2 e^{2ipt} + a_3 e^{3ipt} + \cdots a_n e^{nipt} \cdots$$

the values of the fundamental and first few harmonics have been obtained. The expressions for the harmonics beyond the fourth or fifth become exceedingly complicated. This equation has also been tested experimentally, using an induction coil of very low resistance and the amplitudes of the harmonics as measured experimentally are of the same numerical order of magnitude as those predicted by the above equation. The fundamental and first harmonic check up very closely but as the higher harmonics are reached the discrepancies become greater. It might be stated here that the value of the fundamental is given by

$$I_f = \frac{ke}{R^2 + L^2p^2} \cos(pt - \alpha) \text{ where } \alpha = \tan^{-1}\frac{Lp}{R},$$

and R is the internal output resistance of the tube. This is the same expression as would have been obtained for any alternating current generator, which generated a maximum E.M.F., ke, had internal resistance R and operated into a inductive reactance Lp.

The cases of resistance and inductance, capacity, and a combination of the latter three can easily be derived from the two cases given above. Solutions for these cases with experimental data will be published in the complete paper.

UNIVERSITY OF MINNESOTA,
December 10, 1920.

SECONDARY ELECTRON EMISSION FROM COPPER SURFACES.

BY I. GARNETT BARBER.

IN measurements made upon the secondary emission of electrons from a copper surface which was stimulated by electronic bombardment it has been found that

(1) There is no reflection of electrons at potentials less than the ionizing potential.

(2) The number of secondaries per primary increases up to about 200 volts from which point on it remains nearly constant.

(3) The number of secondaries per primary never exceeds 1.3 in the case of copper.

(4) The re-emission from the surface can be altered by changing the condition of the surface by heat treatment.

(5) The re-emission is apparently decreased by increasing the temperature of the bombarded surface.

RYERSON PHYSICAL LABORATORY.

INELASTIC COLLISIONS OF ELECTRONS IN VAPORS OF CERTAIN COMPOUND MOLECULES.

BY PAUL D. FOOTE AND F. L. MOHLER.

EMPLOYING methods described elsewhere the ionization potential of zinc-ethyl was found to be 12 volts and the resonance potential about 7 volts. The ionization potential of zinc chloride is 12.9 volts, and of mercuric chloride 12.1 volts. Carbon monoxide shows a very peculiar behavior. Two ionization potentials exist at 10.1 and 14.3 volts. Besides these inelastic collisions, electrons undergo the following velocity losses without producing ionization: 6.4, 12.1, 13.6, 19.1, 21.9, 24.6 volts. Some of these are due to successive collisions but no simple interpretation can be offered on the basis of two inelastic impacts as no combination of two numbers can represent these data in a reasonable manner. The vapors of potassium and sodium chlorides at 2 mm. Hg pressure are highly ionized preventing measurements of the ionization potential. From the grating energies of their crystalline salts it appears that their ionization potentials should be around 5 volts. Calcium ionizes at six volts and has a vapor pressure of the same order of magnitude as sodium chloride. Yet calcium vapor is not appreciably ionized by heating to 700° C. The marked contrast in the behavior of sodium chloride and calcium vapors is of interest. Hot sodium chloride vapor gives rise to the emission of the D-lines of Sodium.

BUREAU OF STANDARDS,
WASHINGTON, D. C.

THE EFFECT OF ANGLE OF INCIDENCE ON THE REFLECTION AND SECONDARY EMISSION OF SLOW MOVING ELECTRONS FROM PLATINUM.[1]

BY JOHN T. TATE.

THE reflection and secondary emission of electrons by a metal surface bombarded with slow moving electrons has been investigated by v. Beyer, Gehrts, Campbell, Hull, and others, who have measured the reflection coefficients and the velocity of the reflected and secondary electrons as functions of the velocity of the incident beam. The present paper deals with the effect upon the reflection coefficients of varying the angle of incidence, and with the directional distribution of the reflected and secondary electrons for different angles of incidence.

A narrow beam of electrons from a hot filament was allowed to fall on a plate of platinum capable of rotation about an axis perpendicular to the direction of the beam. The effect of the earth's magnetic field was compensated by placing large Helmholtz coils around the apparatus. All metal parts inside the tube were of platinum. The reflection coefficients were determined by first measuring the current to the plate, i_p, then replacing the plate by a

[1] Presented at the meeting of the Am. Phy. Society, Dec. 28, 29, 30, 1920.

Faraday cage of special design, having an absorption coefficient of about .95, and measuring the current, if received by it. To within a small correction factor the reflection coefficient R would be given by

$$R = \frac{ip - .95\,ip}{if}.$$

The gas pressure throughout the observations was maintained at less than 10^{-6} mm. although the method was such that consistent results for the reflection coefficients were obtained with the pressure as high as 5×10^{-4} mm.

The reflection coefficients so measured showed the usual variation with velocity of the incident beam. Their magnitude depended very greatly upon the treatment of the surface. Without special treatment of the surface the reflection coefficient was usually about .70 at an incident velocity of 8 volts. "Sputtering" the surface of the plate reduced this value to about .30. Covering the surface with a fine platinum gauze reduced the value to .35.

It was found that the reflection coefficient depended very little, if at all, upon the angle of incidence. In one instance, for example, the reflection coefficient changed from .70 to .71 while the angle of incidence was changed from 0° (normal incidence) to 60°. A larger variation of the angle of incidence was not possible since the plate would no longer subtend the entire incident beam.

The distribution of the reflected and secondary electrons was determined by measuring the current received by a sounding electrode mounted to rotate around the plate. Curves of the current to the sound for different angular positions around the plate were plotted. It was found that for all angles of incidence and for incident velocities up to 50 volts the curves showed a maximum reflection or secondary emission in a direction very nearly straight back on the incident beam, falling off to zero in directions parallel to the surface of the plate. The same result was obtained for surfaces which had been sputtered and for a surface covered with a fine platinum gauze.

These results indicate that the direction of the surface normal with respect to the incident beam plays at most a minor part in the mechanism of both reflection and secondary emission.

PHYSICAL LABORATORY,
UNIVERSITY OF MINNESOTA,
December 5, 1920.

A COMPARISON OF THE THERMIONIC AND PHOTOELECTRIC WORK FUNCTION FROM PLATINUM.

BY OTTO KOPPIUS.

ACCORDING to Richardson, the equation governing the emission of electrons from incandescent solids in a vacuum is given by the equation

$$i = AT^{1/2}e^{-b/T},$$

where i is the saturation current at a temperature T from the glowing metal

to an auxiliary electrode, A is a constant of the glowing substance which may be associated with the number of free electrons per c.c. of the body in question, T is the absolute temperature, and b is a characteristic constant of the body which is identified with the work necessary to bring one electron out of the body.

The relation governing the emission of electrons from metals in a vacuum under the influence of light was stated by Einstein in 1905 in the form

$$\tfrac{1}{2}mv^2 = Ve = h\nu - p,$$

where ν is the frequency of the exciting light, h the Planck constant of energy, $h\nu$ is the energy absorbed by the electron from the radiation, p is the work necessary to get an electron out of the interior of the metal, and v is the maximum velocity with which the electron leaves the surface, which can of course be determined by the retarding potential V necessary to just prevent such an escape.

The purposes of the experiments were:

1. To study the variation of the photocurrent from oxide coated and pure platinum filaments with a change in the temperature of the filaments.
2. To see if a constant long wave-length limit for a substance can be determined which is a characteristic of the substance, in particular to test constancy with respect to changes in temperature.
3. To determine the work necessary to get an electron out of the substance photo-electrically, and that necessary to get an electron out of the substance thermionically.
4. To compare the two effects.

It was here proposed to determine both of these effects from the same target in the same tube, since it is well known that the physical conditions of the substance in question affect the values of both b and p very largely. Since the specimen in the work reported here could be kept under identical physical conditions as to pressure, and as to previous history, etc., it was thought that the basis for comparison of the two effects was a more plausible one than the ones usually employed.

The specimen employed were fastened to stout lead-in wires, through which a heating current could be sent. A Faraday cylinder of oxidized copper served to catch the electrons emitted. The temperature of the target was calculated from its change in resistance. The source of ultra-violet light was a Hareus quartz mercury arc. The vacuum usually employed was between $.5 - 1 \times 10^{-6}$ mm. of Hg.

The oxide coated filaments had to be discarded for this comparison work due to the fact that not only the amount of the photocurrent increased with a rise in temperature, but that there was a shift in the long wave-length limit also. The higher the temperature, the longer the waves to which the specimen were photoactive and therefore the smaller the work function as defined in Einstein's equation above. Due to this change, which is most probably due to a change in the surface condition of the specimen, no photoelectric work

function could be taken as being characteristic of these oxide-coated filaments, although Wilson had shown that a definite b, or in other words a definite work function could be ascribed to them in the thermionic effect.

In the case of platinum, however, after thoroughly freeing the plate from occluded gases by heating for hours at a red heat and continuous pumping, a long wave-length limit for the photoelectric effect was found which remained remarkably constant for a range in temperature from room temperature to 500° C. as may be seen from the table below:

TABLE I.

Temperature.	Long Wave-length Limit = λ_0.
20° C.	2571 A.
100° C.	2550
370° C.	2568
490° C.	2564

If we take the value of the long wave-length limit at room temperature as 2571 Å., and then compute the work function as follows:

$$p = h\nu = \frac{6.547 \times 10^{-27} \times 3 \times 10^{10} \times 3 \times 10^{2}}{4.774 \times 10^{-10} \times 2.570 \times 10^{-5}},$$

we get $p = 4.80$ volts. Due to the constancy of λ_0 it is believed that we are dealing here with a constant which is an intrinsic property of the platinum itself.

Unfortunately an accident prevented to carry out the thermionic determination of the work necessary to free an electron. But if we agree with Richardson, who in his book makes a critical study of all the determinations of this constant, the work function for platinum comes to $b = 5.00$ volts.

This shows that the two work functions are very near together, although it cannot perhaps be asserted that they are the same. If the theories underlying the two phenomena are correct, then we should expect the work function in the photo-electric effect to come out larger, since presumably the electrons involved in this phenomenon are first detached from the atoms, and then an additional amount of work is necessary to get the electron out of the metal through the surface. In the thermionic effect, the electrons are supposed to be the free conduction electrons in the metal, which, if emitted, need only be brought through the surface force of the metal. This means that the electrons which are detached by light are the ones in the outer orbits, in which the forces due to the attraction of the nucleus and the repelling forces due to the other electrons are nearly equal and hence necessitate a relatively smaller amount of energy to detach an electron than would be the case where the electron finds itself in the inner orbits.

UNIVERSITY OF CHICAGO.

NEW STRONTIUM AND BARIUM PHOTO-ELECTRIC CELLS.

BY THEODORE W. CASE.

THE Photo-electric Effect in the Oxide Coated Audion Bulb.—Upon looking for a photo-electric effect from the oxide coated filaments of high vacuum Audion bulbs, it was observed that the filament showed slight action both heated and cold. More action was found at the plate when *it* was made negative. A close inspection revealed a brownish deposit on the plate, which was found to be the active material.

Strontium and Barium Cells.—With the above as a starting point, the conditions were determined for the production of barium and strontium photo-electric cells separately. It was found that the active material in the audion bulb was a mixture of the elements: barium, strontium, and possibly some calcium. A cell instantly spoils if a trace of oxygen is admitted to oxidize the metal. The oxide of barium and strontium is not perceptibly photo-electrically active.

Calcium Cell.—It was found to be extremely difficult to obtain a calcium deposit on the plate. However, a trace was obtained. Its maximum spectral sensitivity lies well out in the blue.

Possible Physical Reactions.—Both barium and strontium oxide are known to have the property of forming a dioxide under certain conditions of temperature. If the filament to be heated is coated with calcium oxide as a base and then with barium oxide and the cell exhausted; then either the calcium oxide under these conditions reduces some barium oxide, leaving metallic barium to be carried over to the plate, under the influence of an electric field applied between the filament and plate, or some of the barium oxide reduces some of its neighboring barium oxide under slightly different temperature conditions. Another alternative is that barium oxide is carried over to the plate and somewhere in the journey, or after arrival, is reduced by electron bombardment, leaving pure metal. The difficulty here is in accounting for the lost oxygen.

Spectral Sensitivity.—The barium cell has its maximum action in the light red and orange. If coated at a slightly higher temperature, the maximum is shifted to the yellow and green. This may be due to a very slight amount of calcium coming over.

The strontium cell has its maximum in the green. If coated at the maximum temperature, it is shifted to the blue. This may be due to traces of calcium. The above action was determined in the spectrum of a gas-filled tungsten lamp.

Temperature Effect.—A high vacuum barium cell was constructed so that the plate on which the barium was coated could be heated to a red heat, by passing a current through it. The photo-electric current was increased with increase of temperature, with a maximum increase of about one hundred times, just under red heat. A higher temperature ruined the cell, probably due to oxygen being given off the plate and oxidizing the barium. It has not been determined whether this is a direct temperature effect or only a secondary effect. The strontium cell has not been tested for this effect up to high temperatures, but from ten to one hundred degrees Fah. there is not over three per

cent. change. For this range of temperature the action of the barium cell increases with temperature approximately 2.5 per cent.

Saturation Voltage Effect.—With either a barium or strontium cell, if the applied voltage be increased, the current increases up to a certain voltage, after which further increase of voltage does not apparently affect the current for any light intensity. If this saturation point be used, the photo-electric action is seemingly instantaneous. However, if a voltage under this saturation point be used, the photo-electric action is sluggish, and requires time to reach its maximum. It behaves like the creeping of a selenium cell.

If a saturated voltage be applied and the barium heated, the action is increased, but is sluggish, as though the saturation point had been shifted and as though a higher voltage was required to instantly take care of all the electrons. At this time it has not been determined whether a new saturation point will be found at a higher voltage.

The Photo-electric Current.—The photo-electric current is proportional to the amount of light, up to 4,000 foot candles, to which the cells are sensitive. It has not been possible to check this for higher intensities as yet. The action of the strontium cells has remained constant, within two or three per cent., for several months. The action of the barium cells remains constant provided a suitable filter be used which will eliminate infra-red radiation. The longer wave-lengths spoil the action of the barium cell. In the case of several of these cells whose action has been decreased sixty per cent. by exposing to strong infra-red radiation, it was found possible to bring their action back to normal again by screening out the infra-red and by exposing to strong light of shorter wave-length from either daylight or a Cooper Hewitt lamp. The current from the average cells made here is around one hundred micro amperes, in average sunlight, the sensitive surface being one and one half by five inches. The above characteristics of these cells make them especially adaptable to be used in conjunction with an automatic potentiometer line recording instrument, such as the Leeds & Northrup temperature recorder. Very interesting daylight curves have been obtained here, using cells with different spectral sensitivity.

CASE RESEARCH LABORATORY, AUBURN, N. Y.

A MEANS OF DISTINGUISHING BETWEEN INTRINSIC AND SPURIOUS CONTACT ELECTROMOTIVE FORCES.

BY R. A. MILLIKAN.

DEFINITE proof has been found of the existence of intrinsic contact electromotive forces as well as of apparent contact electromotive forces which are due to transcient surface charges. The equation contact E.M.F. $= (h/e)(\nu_0 - \nu_0')$ states a relation which is found to hold where only intrinsic contact E.M.F.'s are involved. Its failure in any experimental situation indicates the existence of a surface charge which produces an apparent contact E.M.F., the measure of which is the difference between the right and left sides of the foregoing equation.

UNIVERSITY OF CHICAGO.

SIZE AND AGING OF IONS PRODUCED IN AIR.

BY HENRY A. ERIKSON.

IF a current of air containing a thin sheet of ions, obtained from polonium, is passed parallel to and between two plates which are at a difference of potential, it is found that the charge received by a narrow strip in the plane of one of the plates varies with the distance along the stream from the point where the ions enter the field. The distance between the plane of the strip and the initial plane of the ions was 4.5 cm.

Plotting the currents received by the strip as ordinates and the distances along the stream as the abscissæ, the curve obtained resembles the probability curve. At a wind velocity of about 500 cm. per second, the curves obtained for the positive and negative ions are quite similar, the maximum of each coming at the same distance. As the air velocity diminishes the maxima of the curves for the positive and negative ions separate, the maximum for the positive coming at a point further along the stream. The downstream side of the positive curve also lifts up and broadens out. The curve for the negative ions undergoes comparatively only a slight change with change of wind velocity. It is found when the wind velocity is kept constant and at a value which gives curves for the positive and negative ions which are similar and which have the maxima at the same distance, that if the ions are produced at a distance from the point of entering the field, the maxima of the positive and negative curves separate, the positive maximum coming later.

The reasonable interpretation of the spreading of the curves, is that there exists in the air ions of different sizes. The separation of the maxima at lower wind velocity or in the case of older ions is due to the aging of the positive ion whereby it loads up and hence moves more slowly in the electric field.

PHYSICAL LABORATORY,
UNIVERSITY OF MINNESOTA,
December 4, 1920.

THE FORMATION OF NEGATIVE IONS IN AIR.

BY LEONARD B. LOEB.

THROUGH slight modifications of the Rutherford alternating current method of mobility measurement for the carriers produced in air through the action of ultra-violet light on a metal plate disturbing effects due to stray light and organic impurities present in the results of previous workers were eliminated. The mobility curves obtained from these experiments were accordingly capable of being compared with theoretical curves computed on the basis of equations derived by applying the J. J. Thomson theory of ion formation to the Rutherford alternating current method of measurement. The comparisons show good *qualitative* agreement between the theoretical and the observed curves. This is all that can be expected in view of the

difficulty of experimentally fulfilling the simple conditions assumed in the theory. The Thomson constant n (the number of collisions with neutral molecules which are on the average encountered by an electron before it succeeds in attaching to a molecule to form the ion), was found to be about 250,000 for air, if the values for the mobility of the electron and its mean free path assumed are accepted. As it has been shown that the electron cannot attach to the nitrogen molecules, and as n for pure oxygen was found to be about 50,000, one is justified in assuming that it is to the oxygen molecules in air that the electrons attach to form ions.

The apparent contradiction to this theory of ion formation suggested by the work of Wellisch, is shown to be due to an interpretation by Wellisch which is unwarranted by his results. The actual results of Wellisch are shown to be in excellent agreement with the theory of J. J. Thomson.

RYERSON PHYSICAL LABORATORY,
November 27, 1920.

THE STRUCTURES OF THE HELIUM ATOM AND THE HYDROGEN MOLECULE.

BY IRVING LANGMUIR.

THE comparative simplicity of the periodic relationships between the chemical elements, and the Rydberg relation between the atomic numbers of the inert gases, indicates that the problem of atomic structure must be fundamentally much simpler than one would be led to suppose from Bohr's theory. The physical and chemical properties of the elements prove the existence of certain unusually stable configurations of electrons in atoms such as the pair and octet. The stable pair not only characterizes hydrogen compounds and helium atoms but forms the innermost shell of the atoms of all the other elements, and also constitutes the chemical bond that holds atoms together in molecules. The mechanism which is responsible for the remarkable stability and universality of these pairs must be essentially like that which leads to the formation of octets and the groups of eighteen and thirty two which occur in the heavier elements.

Since there appears to be nothing in Bohr's theory to explain such stable groups of electrons, it seems necessary to assume that the electrons in atoms are coupled together in some very definite manner. It is further assumed on the basis of chemical evidence that each electron in an atom has its own separate orbit. There is also much evidence that atoms and molecules of most simple substances have no magnetic moment until brought into a field. On the basis of the classical mechanics I have therefore endeavored to devise models for the simplest atoms and molecules which will be in accord with the chemical as well as the physical properties of the substances. It would seem that the same principles should apply to all elements.

The models proposed for the helium atom and the hydrogen molecule con-

tain two electrons, each of which oscillates back and forth in a nearly semi-circular orbit. The resulting magnetic moment is zero. To make these models give results quantitatively in accord with the ionizing potential of helium or the heat of dissociation of hydrogen, it is necessary to modify the method of applying the quantum theory. Instead of applying the theory to the angular momentum of each electron it is applied to the momentum which, by being transferred from electron to electron, circulates about the nucleus. Because of the fact that the quantum theory has not been successfully applied to the structure of atoms whose electrons are coupled together, there seems to be no good evidence against this modification.

RESEARCH LABORATORY
GENERAL ELECTRIC COMPANY.

THE CUBIC SHAPES OF CERTAIN IONS, AS CONFIRMED BY X-RAY CRYSTAL ANALYSIS.

BY WHEELER P. DAVEY.

IN order to account for the chemical properties of the elements, Lewis, Born and Landé, and Langmuir[1] assigned to each element a definite arrangement of electrons. The resulting atomic shapes depend upon the position of the element in the periodic table. The formation of ionic compounds results in a transfer of electrons from the "positive" element to the "negative" element. As a result of this transfer, ions of $\overset{+}{\mathrm{Na}}$, $\overset{+}{\mathrm{K}}$, $\overset{++}{\mathrm{Mg}}$, $\overset{++}{\mathrm{Ca}}$, $\overset{--}{\mathrm{O}}$, $\overset{--}{\mathrm{S}}$, $\overset{-}{\mathrm{F}}$, and $\overset{-}{\mathrm{Cl}}$ each have, according to the theory, an outer shell of eight electrons whose mean positions are at the corners of a cube. The "shape" of these ions is therefore supposed to be that of a cube with rounded corners; $\overset{+}{\mathrm{Rb}}$, $\overset{+}{\mathrm{Cs}}$, $\overset{++}{\mathrm{Sr}}$, $\overset{++}{\mathrm{Ba}}$, $\overset{++}{\mathrm{Ni}}$, $\overset{-}{\mathrm{Br}}$, and $\overset{-}{\mathrm{I}}$ are probably also cubic. $\overset{+}{\mathrm{Tl}}$ and $\overset{++}{\mathrm{Pb}}$ are spheres with flat spots.

It is the purpose of the present paper to consider the shapes of these ions in relation to their arrangement in space in crystals composed of equal numbers of each of two kind of ions, (*i.e.*, NaCl or MgO). The arrangement of these ions in the crystal depends upon their shape, subject to the condition that each ion must be symmetrically surrounded by oppositely charged ions.

Only two kinds of cubic lattices are possible for these compounds:

(*a*) Simple cubic (*i.e.*, NaCl structure). The ions are arranged each on a face-centered cubic lattice. These two lattices interpenetrate so as to produce a simple cubic lattice. The interpenetration of two such lattices to form a diamond lattice would give perfect symmetry, but the cubic shape of the ions would not permit of as close packing as the simple cube, so that such a lattice would not be as stable as the simple cube. From the viewpoint of a kinetic theory of crystal growth, we must therefore assume that an ion newly arrived on the crystal face in a "diamond" position is more likely to leave it again than if it had arrived in a "simple cubic" position, so that the re-

[1] Lewis, Jour. Am. Chem. Soc., 38, 762, 1916. Born and Landé, Verk. deut. physik Ges., 20, 210, 230, 1918. Langmuir, Jour. Am. Chem. Soc., June, 1919.

sulting crystal is simple cubic. The diamond itself crystallizes as it does only because of the tetrahedral shape of the C atoms, and their tendency to complete their octets. CaF_2 crystallizes in a modified diamond form in spite of the fact that $\overset{+}{Ca}$ and $\overset{-}{F}$ are both cubes, because this is the closest packing which will give a symmetrical arrangement of two fluorine ions to one calcium ion.

All the halides of Na, and K, and MgO, CaO, CaS and BaS have previously been reported in the literature as showing simple cubic structure. To these may now be added RbBr and NiO, having elementary simple cubes of sides respectively 3.465 Å. and 2.07 Å.

(*b*) Body-centered cubic structure. The ions are arranged each on a simple cubic lattice. These two lattices interpenetrate to produce a body-centered cubic lattice. Only one salt composed of cubic ions is yet known which has this structure, — CsCl. As the other halides of Cs have not been investigated it cannot be stated whether this is due to some peculiarity in the shape of the Cs atoms.

The diffraction pattern of TlCl is that of a simple cube of TlCl groups, *i.e.*, the crystal is a body-centered cube of ions. PbS is a simple cube of ions. According to Langmuir's theory $\overset{+}{Tl}$ and $\overset{+\ -}{Pb}$ have only 26 electrons on their outer surfaces, out of 32 necessary to make that shell into a sphere. In other works, their shapes may be regarded as being generally spherical but with six flat spots. These flat spots make the surface simulate a cube, so that the cubic structure of TlCl and PbS is explained.

To summarize: A study has been made of the crystal structure of compounds formed by equal numbers of each of two oppositely charged ions which are cubic according to the theory of Lewis, Born and Landé, and Langmuir. New data added to that at present available in the literature allow this study to cover ions whose atomic numbers range from 8 to 82. The results of these purely physical experiments contribute towards an experimental verification of the theory of atomic shapes, which was originally devised to explain the chemical properties of the elements.

RESEARCH LABORATORY,
GENERAL ELECTRIC COMPANY,
SCHENECTADY, N. Y.

THE CRYSTAL STRUCTURE OF TWO RARE HALOGEN SALTS.

BY WHEELER P. DAVEY AND FRANCES G. WICK.

THE crystal structures of CsCl and TlCl have been studied by the powder method of Hull, with the following results.

CsCl gives a diffraction pattern of a simple cube of side 4.12 Å. The density of the elementary cube shows that one CsCl group is associated with each point of the cubic lattice. CsCl is, therefore, to be thought of as a simple cube of Cs ions with a Cl ion at the center of each cube. This structure is different from that assumed by Bragg[1] from crystallographic data, and the

[1] W. L. Bragg, Phil. Mag., Aug., 1920.

distance observed between Cs and Cl atoms can not be calculated from the atomic dimensions assumed by Bragg.

TlCl gives a diffraction pattern identical with that of CsCl except that this side of the elementary cube is 3.85 Å. Its density shows an atomic arrangement identical with CsCl. The atomic distances are not consistent with Bragg's volume of thallium.

RESEARCH LABORATORY,
GENERAL ELECTRIC COMPANY,
SCHENECTADY, N. Y.

MULTIPLE VALENCY IN THE IONIZATION BY ALPHA RAYS.

BY T. R. WILKINS.

USING the Millikan Oil-drop apparatus, the ionization produced by slow alpha rays from polonium has been examined in the case of several gases. It has been found possible to produce doubly charged helium ions and the percentage of doubles produced has been shown to be a function of the speed of the alpha rays. The problem has also been attacked mathematically to rule out what have been classed as "spurious doubles" in earlier work. The percentage of doubles under optimum conditions has run as high as 15 per cent. of the ions caught.

BRANDON COLLEGE,
MANITOBA.

ADDITIONAL EXPERIMENTS ON THE NATURE OF THE MAGNETIC MOLECULE.

BY S. J. BARNETT AND L. J. H. BARNETT.

IN earlier papers it has been shown that the rotation of an electron ring, or a magneton, whose angular momentum bears to its magnetic moment a definite ratio R, about any axis at the angular velocity N revolutions per second is magnetically equivalent to placing it in a magnetic field with intensity H directed along this axis such that $H = 2\pi RN$.

Therefore, if all the magnetic elements in a body are alike, rotating the body at the angular velocity N r.p.s. will produce the same magnetic moment as placing it in a magnetic field with intensity $2\pi RN$ gauss.

For a ring of negative electrons of the familiar type $2\pi R = 4\pi(m/e) = -7.1 \times 10^{-7}$ e.m.u. Hence if a ferromagnetic body owes its magnetic properties to such a ring, its rotation must be equivalent to placing it, at rest, in a magnetic field with intensity $H = -7.1 \times 10^{-7}\ N$ gauss directed along the axis of rotation.

In two investigations on cold-rolled steel made in 1914 and 1915 by a method of electromagnetic induction we found the above theory verified except that numbers 3.6 and 3.1 were obtained in place of 7.1. Another investigation, made in 1916 and 1917, on steel, cobalt, and nickel, by a magnetometer method, also gave numbers smaller than 7.1.

A new and extended series of experiments has now been made on steel, soft iron, cobalt, and Heusler alloy, by a considerably different magnetometer method, and with additional precautions to eliminate systematic errors due to torsion and eddy currents. In every case a number not greater than about one half of 7.1 has been obtained. The experimental method is still being improved, but it is believed that all systematic errors have already been so far eliminated as to justify the conclusion that one of the two following alternatives must be true: (1) If negative electricity alone is responsible for ferromagnetism, it must exist in some form of orbital ring or magneton for which R has a smaller numerical value than that calculated for orbital rings from the value of m/e attributed to electrons of the familiar type; or (2) positive electricity in orbital rings or in magnetons must be partially responsible, as the rotation of positive magnetons or electron orbits must produce a magnetic moment opposite to that produced by rotating the negative magnetons or orbits, whose effect is preponderant.

CARNEGIE INSTITUTION,
WASHINGTON.

ON THE APPLICATION OF INTERFERENCE METHODS TO ASTRONOMICAL MEASUREMENTS.

BY A. A. MICHELSON.

IN the number of the *Philosophical Magazine* for July, 1890 (**30**, 1), a method was described for the measurement of the angular magnitude of astronomical objects such as the diameter of planetoids and satellites and the distance between double stars, when these are beyond the powers of the largest telescopes, and the hope was there expressed that it might not be impossible thus to measure the diameter of the fixed stars.

Briefly, the process consists in utilizing only the two portions of a large objective at opposite ends of a diameter. The interference fringes at the focus under these conditions will be a series of equidistant interference bands which are most distinct with a source subtending an infinitesimal angle. For an object presenting an appreciable angle the visibility is less and may become zero—the exact relation being readily expressed for any given distribution of light in the source.

A series of observations was taken on the satellites of Jupiter at the Lick Observatory, in 1891, with results which amply confirmed the practicability and accuracy of the method.

It is clear, however, that as in all probability the stars present an angular diameter less than one hundredth of a second, it would be almost hopeless to make such measurements, utilizing the largest telescope in existence; for it would require a distance between the apertures of at least 10 meters to observe the vanishing of the fringes. While such a large telescope would be entirely out of question, the interferometer arrangements figured in the article referred

to may serve the purpose, as there is theoretically no limit to the effective base line and practically only that which depends on the atmospheric disturbances.

With a view to testing the effect of these, a trial was made (August 25, 1919) with the 40-inch refractor at Yerkes Observatory, using two apertures 4 inches by 5 inches at opposite ends of a diameter. The result was very encouraging, the interference bands being remarkably steady, notwithstanding the relatively poor "seeing"—2 to 3 on a scale of 5.

On invitation from Dr. George E. Hale the test was applied (September 18, 1919) to the 60-inch reflector of the Mount Wilson Observatory and then to the 100-inch reflector, and in both cases the experience at the Yerkes Observatory was confirmed. (*Astrophysical Journal*, **51**, 257, 1920.)

In December, 1919, and the months following, Anderson, using this method, obtained measures of the distance and position angles of the components of Capella with great accuracy (*Astrophysical Journal*, **51**, 260, 1920). Upon the author's suggestion, an interferometer beam 20 feet long, provided with movable auxiliary mirrors, was then constructed to test conditions of interference at distances greater than the diameter of the one hundred inch mirror itself. In August, 1920, fringes were obtained with separations of the mirrors as great as 18 feet, the visibility of the fringes for Vega at this distance being as great as that at 6 feet.

Meanwhile, Eddington, Russell, and Shapley had obtained values for the diameter of a number of stars based on estimates of apparent surface brightness, and their results indicated that several of these lay within the range of the 20 foot beam. α Orionis in particular was so large that Merrill investigated it with the apparatus used in the measurement of Capella and found a definite decrease in visibility for the maximum separation of the slits (100 inch aperture), this holding true for all position angles.

Observations were made at the Mt. Wilson Observatory by Mr. F. G. Pease on December 13, 1920, with the outer mirrors of the 20-foot beam at 121 inches separation. No fringes were visible on γ Orionis, while observations on γ Orionis before, and on α Canis Minoris afterwards yielded strong fringes with practically no change of setting. All measures were checked by Dr. Anderson. The seeing was very good on this night, but poor on the following nights, and it appears that better conditions are required than when working with fringes produced by apertures placed directly before the telescope. Nevertheless, observations made December 14–17 indicate that α Ceti, α Tauri and β Geminerum will come within the range of the 20-foot beam.

Assuming that the effective wave-length for α Orionis is λ 5750 its angular diameter from the formula $\alpha = 1.22\lambda/d$ proves to be 0″.047 and with Schlesinger's parallax of 0″.016 its linear diameter turns out to be 271×10^6 miles, or slightly less than that of the orbit of Mars.

The uncertainty of the present measurement is about 10 per cent. The effect of a possible darkening at the limb, which has been disregarded, would tend to make the measured results too small.

UNIVERSITY OF CHICAGO AND MT. WILSON SOLAR OBSERVATORY.

SOME PECULIARITIES IN ENERGY DISTRIBUTION BY SPECULUM GRATINGS.

BY L. R. INGERSOLL.

IN a recent paper (*Astrophys. Jour.*, April, 1920) the writer has described experiments which show that when the directly reflected light (*i.e.*, central image) from a speculum grating is examined it is found markedly deficient in energy of such wave-length as is emerging tangentially from the grating in the first or higher order spectrum. The effect is confined to the polarization with electric vector perpendicular to the rulings and is in general accord with the Rayleigh-Voigt theory. This theory also predicts sharp maxima of energy of this polarization in any spectrum for such wave-lengths as are emerging tangentially in any higher order, while the tangentially diffracted radiation itself should be of much greater intensity for this polarization than for the other.

The last prediction of the Rayleigh-Voigt theory is readily verified by casual examination of almost any speculum grating. As to the maxima in the various

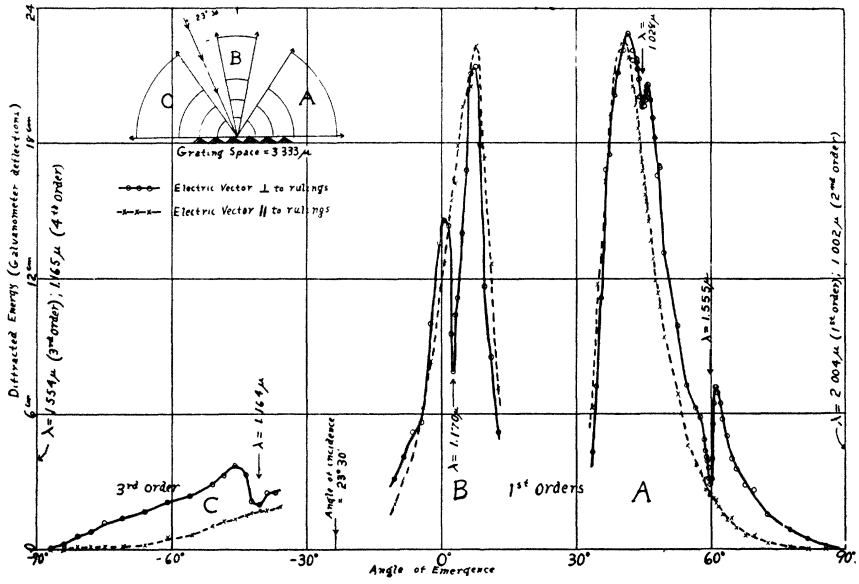

Fig. 1.

Spectrum energy curves, for both azimuths of polarization, as determined with a speculum grating of 300 lines per millimeter.

spectra, however, the writer has carried out experiments on a number of gratings and over a wave-length region from .5μ to 2μ and finds that instead of maxima there are sharp *minima* at such wave-lengths, as the accompanying figure shows. The radiation in this case is incident at an angle of $(-)23° 30'$ on a grating of 300 lines per mm. It will be noted that the minimum at about 60° corresponds almost exactly with the wave-length emerging tangentially in the third order on the other (negative) side. Similarly the minima in the

other first order and in the third order correspond to the fourth order tangential on the negative side, while the agreement of the minimum at $\lambda = 1.028\mu$ with the second order tangential on the positive side is not quite so good.

A simple explanation of these minima can be arrived at if it is noted that the energy which is diffracted nearly tangentially (*i.e.*, between angles of, say, 70° and 90°) is, because of the high dispersion for nearly tangential emergence, coming from a very narrow wave-length region. This excess of perpendicularly polarized energy will accordingly be taken from spectra of other orders and may produce a more or less sharp minimum at this wave-length. The effect seems to show best for wave-lengths somewhat longer than the visible although some special gratings show it in this region also.

In many cases these minima are accompanied by maxima, as appears in the accompanying figure at angle 61°. These might superficially be regarded as in accordance with the Rayleigh-Voigt theory were they not in every case at longer than the predicted wave-lengths. In some cases, particularly for very deeply ruled gratings, the minima themselves are found at longer wave-lengths than the above reasoning would predict. The explanation of this is not clear but probably depends on peculiarities of groove form.

UNIVERSITY OF WISCONSIN.

THE COLORATION OF GLASS BY ULTRA-VIOLET LIGHT.

BY J. B. NATHANSON.

IT has long been a matter of observation that glass globes surrounding arc lamps become colored after long usage. This coloration has been attributed to the ultra-violet radiations coming from the arc and bringing about a certain chemical reaction in the glass. After much experimentation a glass has been produced which it was thought, would not become colored with prolonged exposure to ultra-violet light.

In order to put this matter to an experimental test, a composite globe was made up as follows: An old type of globe as well as a new type globe were each cut into halves, and the composite globe then built up of a half from each globe. Inside of this globe was placed a quartz mercury arc operating at about 87 watts. This arc was placed equally distant from the two different halves of the globe, so that these two kinds of glass would be equally exposed to the ultra-violet radiations. A small piece of tin foil was pasted on the inside of each half of the globe, so as to shield a portion of each glass from those radiations.

The mercury arc was operated for periods of time varying from one to nine hours. After an exposure of 50 hours, the old type globe appeared slightly purplish in color when viewed normally with a white paper backing. With further exposure this purplish color was in creased. At the end of 200 and 400 hours exposure, spectro-photometric data were obtained showing the spectral transmission of this glass. The test spot chosen was located close to

the spot covered by the tinfoil. For purposes of comparison, the spectral transmission curve was also obtained for the spot covered by the tinfoil.

The data obtained for the exposed glass, as compared with that for the unexposed portion of the glass, showed a relatively greater absorption for the region 0.51 to 0.57 microns, than for any other portion of the spectrum. For example in the case of wave-length 0.53 microns, the percentage transmission of the glass before exposure, after 200, and 400 hours exposure, are 89.0, 85.0, and 82.7 respectively. As might be expected therefore, the purplish color is due to an absorption in the green portion of the spectrum. There is some absorption in the red, and very little in the violet.

The new type of glass globe showed no trace of coloration after 400 hours of exposure to the ultra-violet radiations. There was no detectable difference between the unexposed and exposed part of the glass.

To produce the coloration observed in the case of the old type of glass globe after 400 hours exposure, an approximate calculation shows that 4.5 Joules of ultra-violet energy are required per square centimeter of glass surface.

The above is published by permission of the director of research, Macbeth-Evans Glass Company.

CARNEGIE INSTITUTE OF TECHNOLOGY.

A STRAINED GLASS ELLIPTIC POLARIZER AND ANALYZER.

BY A. DE FOREST PALMER.

THE instrument herein described has been developed primarily for the purpose of detecting and measuring small changes in the ellipticity of polarized light. Two slips of microscope cover glass, 25 millimeters long, 4.7 millimeters wide and .226 millimeter thick, are so mounted that each covers one half of the field of view and that the dividing line between them is horizontal. One of the slips can be strained horizontally by a steel spiral spring the tension of which is regulated by a micrometer screw. The other slip is mounted on adjusting screws that change its position without producing strain. The contiguous edges of the slips are ground and polished to an optical flat. These slips form a half-shade elliptic polarizer and the movable slip is so adjusted that the division line disappears when the intensity in the two parts of the field is the same. A third slip, of the same thickness as the other two but eleven millimeters wide and covering the whole field of view, is mounted back of the half-shade and can be strained in a vertical direction by a steel spiral spring controlled by a micrometer screw. This slip serves as a compensator or analyzer. Both half-shade and compensator are so designed that the stresses are pure tensions and the strains are uniform. The half-shade spring produces a tension of .285 gram's weight per micrometer division and the compensator spring a tension of 2.04 grams' weight per micrometer division.

When the above combination is placed between crossed Nicols, with their planes of polarization at forty five degrees to the vertical, and the observing

telescope is focused on the half-shade the field of view will remain dark so long as there is no strain in any of the glass slips. But when the half-shade slip is stressed the light transmitted by it becomes elliptically polarized and one half of the field, say the lower, becomes bright. If the compensator slip is now stressed, it produces an ellipticity in the opposite sense to that of the half-shade, and the lower half of the field becomes darker while the upper half becomes lighter. Consequently the intensity in the two parts of the field can be equalized by properly adjusting the tension on the compensator slip. If the differential order of the half-shade is represented by N_1 and that of the compensator by N_2, it can be proved that balance occurs when

$$N_1 = 2N_2, \tag{1}$$

and that this condition is independent of the relative orientations of the polarizing and analyzing Nicols so long as the axes of strain in the glass slips are at right angles to one another. However, the sensitiveness of the combination is much greater when the planes of polarization of the Nicols are at forty-five degrees to the axes of strain.

The glass slips were calibrated by placing a quarter wave plate between them and the analyzing Nicol with its axes parallel to the planes of polarization of the Nicols. Under these conditions the differential order of the slips can be computed from the angle through which the analyzing Nicol must be turned to produce extinction. Accuracy in this method can be attained only with very intense and nearly monochromatic light. For this purpose a 1000-watt gas-filled tungsten lamp was used with a light filter giving maximum intensity at wave-length 584 $\mu\mu$. The half-shade and compensator slips were calibrated independently by this method and the values thus obtained were adjusted, by a series of balance observations, to satisfy equation (1). N_1 and N_2 were found to be linear functions of the tension expressible by the relations

$$N_1 = 2.00\, T_1 \times 10^{-6} \quad \text{and} \quad N_2 = 6.112\, T_2 \times 10^{-6}, \tag{2}$$

where T_1 and T_2 are the tensions on the slips expressed in micrometer divisions. The maximum tension used on the half-shade was 1,100 divisions and that on the compensator 182 divisions. Consequently the largest value obtained for N_1 was .0022 and that for N_2 was .00111.

If the light incident on the half-shade is elliptically polarized, balance will occur when

$$N_1 = 2(N_2 + N_3), \tag{3}$$

where N_3 is the differential order corresponding to the ellipticity of the incident light. Any value of N_3, or any change in this value, within the range of the instrument can be easily determined by equations (2) and (3). The final balance can be obtained by varying either N_1 or N_2, but greater sensitiveness is usually obtained by varying N_2. When N_3 is greater than the range of the instrument it must be partially compensated by a suitably chosen mica plate placed with its axes parallel to the axes of strain in the glass slips.

For the purpose of making an estimate of the sensitiveness and accuracy of the instrument, the micrometer screw controlling N_1 was set arbitrarily and a number of independent determinations of the tension T_2 necessary to produce balance were made. The values of N_1 chosen were about equally spaced throughout the range of the instrument. The maximum deviation of a single observation of T_2 from the mean of its series was one micrometer division; the average deviation was .31 division. These deviations correspond to errors in N_2 of 6×10^{-6} and 2×10^{-6} respectively. Consequently the limiting sensitiveness of the instrument corresponds to a phase difference of about five millionths of a wave-length of the light used and to a path difference of about 3×10^{-9} millimeter.

BROWN UNIVERSITY,
December 13, 1920.

THE BLACKENING OF A PHOTOGRAPHIC PLATE AS A FUNCTION OF INTENSITY OF LIGHT AND TIME OF EXPOSURE.

BY P. S. HELMICK.

EXPRESSING the blackening of a photographic plate in the form[1] $D = 1/a \operatorname{Log}_e [b - (b-1)e^{-t.10^{-A+B \operatorname{Log}_{10} I + C \operatorname{Log}_{10}^2 I}}]$ an algebraic and a graphical method are shown for determining the parameters a, b, A, B, and C.

The "p" of Schwarzschild's expression ($I \times t^p$ = const. for equal blackening)[2] is equal to $(B + C \operatorname{Log}_{10} I)^{-1}$.

To test this method, exposures were made with light of 450 $\mu\mu$, 550 $\mu\mu$, and 650 $\mu\mu$ upon Slow, Rapid, and Very Rapid plates. With variations in times of exposure from 1 sec. to 15 min., and variations in intensities from $10^{-2.0}$ watts/sq. m. to $10^{-4.3}$ watts/sq. m. the formula fits the experimental facts fairly well for densities between 0.2 and 5.0.

PHYSICAL LABORATORY,
THE STATE UNIVERSITY OF IOWA.

A DETERMINATION OF YOUNG'S MODULUS AND OF THE COEFFICIENT OF SIMPLE RIGIDITY OF NATURAL HEXAGONAL CRYSTALS OF SELENIUM.

BY L. P. SIEG AND R. F. MILLER.

TO obtain the five constants necessary for the description of the elastic nature of a hexagonal crystal one would have to obtain, as shown by Voigt,[3] at least three specimens; one with the principal crystallographic axis parallel to the greatest dimension, one with it at 45°, and one cut transversely. The crystals used in the present work were made by sublimation a few years

[1] An empirical modification of Hurter and Driffield's original formula. See Jour. Soc. Chem. Ind., 9, 455, 1890.

[2] Astrophys. Journ., 11, 89, 1900.

[3] Ann. d. Phys., 16, p. 408, 1882. Also 29, p. 604, 1886.

ago by a former colleague, F. C. Brown. These crystals are beautifully regular hexagons with their length parallel to the principal axis. As it appeared impossible to obtain specimens of sufficient size oriented in the second two directions, mentioned above, it was not possible to determine the five constants, so merely two of the gross constants; viz., Young's modulus and the simple rigidity, were obtained. The values of these as determined are 5.8×10^{11} dynes/cm.^{2}, and 0.64×10^{11} dynes/cm.^{2}, respectively. The large ratio of these two; viz., 9.1 is unusual, and disturbing, for theory, and results for most common substances, indicate that this ratio should not be far from three.

The advantage is pointed out of using elements in crystalline form whenever possible, for the determination of elastic constants, as the results thus obtained should show more agreement among themselves, and should be more useful in the study of the structure of matter than results from heterogeneous mixtures of crystalline and amorphous states, as found in drawn wires, could ever possibly be.

STATE UNIVERSITY OF IOWA,
December, 1920.

THE OPTICAL DISPERSION AND THE CRYSTAL STRUCTURE OF ROCK SALT AND SYLVITE.

BY H. H. MARVIN.

LARMOR has developed the dispersion formula

$$\frac{n^2 - 1}{n^2 + a} = \frac{K - 1}{K + a} + \frac{c_1}{\lambda^2 - \lambda_1^2} + \frac{c_2}{\lambda^2 - \lambda_2^2} + \cdots$$

connecting the refractive index n of a transparent medium with the wave-length λ of radiation propagated through it, and has deduced the value $a = 2$ for the constant in the first term in the case of isotropic substances. This value has been confirmed by the author by consideration of dispersion data of CCl_4, $SiCl_4$, $TiCl_4$, $SnCl_4$, and $SbCl_5$. Maclaurin has found, however, that values $a = 5.51$ and $a = 1.04$ are required to fit the formula to the dispersion data for rock salt and fluorite, and has surmised that the deviation from the value 2 is due to the crystalline nature of these substances.

Calculations now in progress show that the dispersion data for rock salt and sylvite may be fitted by the Larmor-Maclaurin formula with the value $a = 6$, and a greater value might be used. The formulæ show remarkable similarity. The mean experimental values, $K = 5.92$ for rock salt and $K = 4.85$ for sylvite, are used for the dielectric constants. Three resonance wave-lengths, λ_1, λ_2, and λ_3, are needed in each case; the values are approximately 0.113 μ, 0.154 μ, 51.7 μ for rock salt, and 0.118 μ, 0.159 μ, 61.6 μ for sylvite.

The formula may be deduced from electron theory. The medium is considered as an aggregation of oscillators which are set into forced vibration by an electromagnetic wave. Each oscillator, when displaced, is acted on by a

force arising within the atom, which accounts for the resonance wave-lengths. There is also a force due to oscillators of other classes in neighboring atoms, which acts to increase the displacement. The force exerted on an oscillator of class 1 by those of class 2 is given by a term

$$-\frac{4\pi}{a+1}\cdot e_1 N_2 e_2 (x_1 - x_2),$$

in which N_2 gves the concentration of oscillators of class 2, e_1 and e_2 the charges, and x_1 and x_2 the displacements.

The value $a = 6$ in the dispersion formula requires the value 1.8 for the proportionality factor $4\pi/(a+1)$. Larmor deduced the value $4\pi/3$ by "smoothing out" the structure of the medium so that the atom under consideration lies in the center of a cavity surrounded by oscillators uniformly distributed. This is the case for any cavity of symmetrical shape.

In the crystal structure of rock salt or sylvite, each Cl atom has for its closest neighbors six Na (or K) atoms located at the vertices of a regular octahedron. These are surrounded by a similar concentric shell containing only Cl atoms, and so on. If these atoms are considered to be simple doublets, the proportionality factor is zero. The value 1.8 required may be obtained by supposing that about 0.43 part of the oscillators are distributed, and the remainder are penned up in the atoms. The required value can also be worked out by assuming that the oscillators having ultra-violet resonance wave-lengths are the electrons of the outer shells of Langmuir atoms, provided the radius of the shell is about one fourth the distance between the centers of the closest atoms, and that the electrons are constrained to move along meridians on the shell when the electric force acts along the polar axis.

The latter assumption is supported by the calculation from the values of the constants c_1 and c_2 in the dispersion formula that the number of oscillators belonging to resonance wave-length λ_1 is almost seven times the number belonging to λ_2 in both crystals. W. L. Bragg has recently pointed out that the Cl atom probably completes its outer shell of eight electrons by borrowing one from Na or K. The borrowed electron might easily occupy an exceptional position, and have a different resonance frequency from the other seven electrons in the shell.

BRACE LABORATORY OF PHYSICS,
UNIVERSITY OF NEBRASKA.

THE INTENSITY OF LIGHT TRANSMITTED THROUGH A DEEP SLIT.

BY L. P. SIEG AND A. T. FANT.

AS indicated by Rayleigh,[1] practically every slit is a "Deep" slit, and a "Thin" slit can be obtained only with the greatest difficulty. Rayleigh used for the latter a fine scratch in a thin silver film deposited upon glass. In

[1] Roy. Soc. Lond. Proc., A, 89, 1913–14, p. 194.

the present work experiments were made with a series of slits with steel jaws, varying in depth from that of thin safety razor blades to approximately 2.5 cm. The intensity of the transmitted light was experimentally determined as a function of the width and depth of the slits, and of the wave-length of the light. For narrow slits, the narrowness depending on the depth and wave-length, practically complete polarization, with the electric vector parallel to the length of the slit, was noted, but exact measurements were deferred to a later work. On the basis of diffraction, multiple reflections, and the alteration of the ratios of the two electric vectors due to the latter, a simple theory was developed, the results of which agree well with the experimental results. The chief fact derived from the experiments is that for narrow slits the total amount of light transmitted is not, even approximately, proportional to the opening, and that therefore the use of such slits for photometric purposes will lead, unless proper corrections are made, to erroneous values for the intensity of the transmitted light.

THE STATE UNIVERSITY OF IOWA,
December, 1920.

THE LINES OF ELECTRIC FORCE OF A SYSTEM OF ELECTRIC POLES MOVING ALONG THE SAME STRAIGHT LINE.

BY H. BATEMAN.

LET the line along which the electric poles move be taken as axis of x. The lines of force may be found with the aid of the following theorem. If ξ denotes the distance from the origin at time τ of one of the poles, the field vectors in the electromagnetic field produced by the pole may be expressed in the form

$$\begin{aligned} E_x &= -\frac{\partial(\alpha,\beta)}{\partial(y,z)}, & H_x &= \frac{1}{c}\frac{\partial(\alpha,\beta)}{\partial(x,t)}, \\ E_y &= -\frac{\partial(\alpha,\beta)}{\partial(z,x)}, & H_y &= \frac{1}{c}\frac{\partial(\alpha,\beta)}{\partial(y,t)}, \\ E_z &= -\frac{\partial(\alpha,\beta)}{\partial(x,y)}, & H_z &= \frac{1}{c}\frac{\partial(\alpha,\beta)}{\partial(z,t)}, \end{aligned} \qquad (1)$$

where α = const., β = const. are the equations of a line of electric force, and

$$\alpha = \frac{ce}{4\pi}\frac{x-\xi-v(t-\tau)}{v(x-\xi)-c^2(t-\tau)}, \qquad \beta = \tan^{-1}\frac{y}{z},$$

$v = \xi'(\tau)$ is the velocity of the pole at time τ, e, the electric charge associated with the pole, c the velocity of light. The time τ is given as a function of x, y, z and t by means of the relation

$$[x-\xi(\tau)]^2 + y^2 + z^2 = c^2(t-\tau)^2, \qquad \tau \leq t.$$

For a number of poles the expressions (1) still hold but

$$\alpha = \Sigma\frac{ce_s}{4\pi}\frac{x-\xi_s-v_s(t-\tau_s)}{v_s(x-\xi_s)-c^2(t-\tau_s)}, \qquad \beta = \tan^{-1}\frac{y}{z}.$$

The linesofforce for anumber of such poles may be derived from those for a single pole by a graphical method similar to that used in the case of electrostatic fields. The lines of force in a number of cases are shown in the diagrams.

CALIFORNIA INSTITUTE OF TECHNOLOGY.

A HIGH FREQUENCY RESISTANCE STANDARD.

BY JOHN G. FRAYNE.

A HIGH frequency resistance standard should possess negligible inductance and capacity and be free from "skin effect." The ideal resistance would be a short straight wire of small diameter, for its inductance would be negligible, the capacity between it and the other parts of the circuit could be made as small as desired, and the "skin effect" would be negligible if the diameter were sufficiently small. However, no ordinary wire will possess a greater resistance than 10 ohms (say) per centimeter, and in order to obtain a pure resistance of say 5,000 ohms, so much wire will be necessary, that inductance and capacity effects are certain to be introduced.

A spluttered quartz fiber seems to meet all the above requirements. Its high volume resistivity makes it possible to use a very short length for even a resistance of the order of 10,000 ohms. In this case the whole wire is "skin," and the "skin effect" is infinitesimally small.

Platinised quartz fibers about 10 centimeters long and in the neighborhood of one hundredth millimeter diameter, mounted on hard rubber bases and immersed in acid-free paraffin oil were found to be the best resistances from the standpoint of usefulness and reliability. In the case of thin metallic films it is known that they exhibit a negative temperature coefficient, and in the case of these comparatively heavy fibers the temperature coefficient appears to be practically zero. The fact that platinum will not oxidize easily also tends to preserve the constancy of the resistance.

From Lord Rayleigh's formula for resistance of wires at high frequencies,

$$R_n = R_0 \sqrt{\frac{p\mu\pi d^2}{8\rho}},$$

where $p = 2\pi x$ frequency, d = diameter, μ = magnetic permeability and ρ = volume resistivity of wire, it can be seen that the small diameter and the high resistivity of platinum in the then film condition make the skin effect negligible. Actual calculations show the value of R_n/R_0 to be about 1.001 for a frequency of about 10^6 cycles per second.

The following table shows the constancy of the resistances over a period of two months.

1920.

Specimen No.	May 24.	May 30.	June 10.	June 21.	July 6.	July 18.
I	464	464.3	465	465.5	465	466
II	963	962.5	962.5	964	963.5	963
III	629.8	630.4	631.6	632.4	633	633

The temperature of the oil bath was practically constant when these measurements were made. A slight fluctuation is noticeable, but the true resistance can always be measured on an ordinary Wheatstone Bridge. These measurements were made during a period when the fibers were being constantly used in connection with experimental research on vacuum tubes. Currents as high as 65 milamperes were carried by the fibers which did not appear to show any apparent deterioration or change in resistance as a result. Their apparent ruggedness and their ability to carry such large currents make it seem possible that they could be of immense value in high frequency measurement work.

UNIVERSITY OF MINNESOTA,
December 10, 1920.

THE EFFECT OF A SUPERPOSED CONSTANT FIELD UPON THE ALTERNATING CURRENT PERMEABILITY AND ENERGY LOSS IN IRON.

BY ALVA W. SMITH.

BY the use of a suitable bridge, measurements have been made upon the apparent inductance and resistance of a coil containing an iron core when this core is under the action of a constant field. From these data, the alternating current permeability, iron loss and a quantity—the direct current induction multiplied by the alternating current permeability—which is pro-

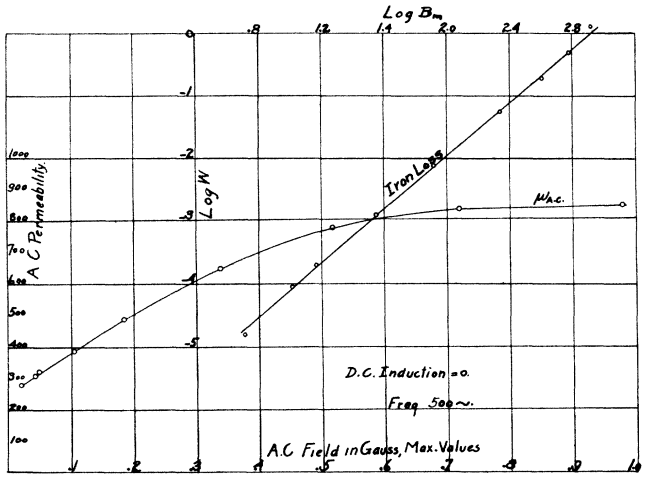

Fig. 1.

portional to the useful mechanical force per unit current when the iron is used as the core of a polarized electromagnet, were calculated.

The test specimen was in the form of a ring built up from laminations cut from transformer plate. All of the results herein given were obtained with an alternating current of 500 cycles, giving fields ranging from 0.01 to 1.0 gauss.

Fig. 1 represents the alternating current permeability as a function of the alternating field with no superposed field. From an initial value of 250, the permeability rises to a maximum for a field which is approximately equal to

that for which the direct current permeability reaches its maximum, but the alternating current permeability has a maximum value of about one fifth of

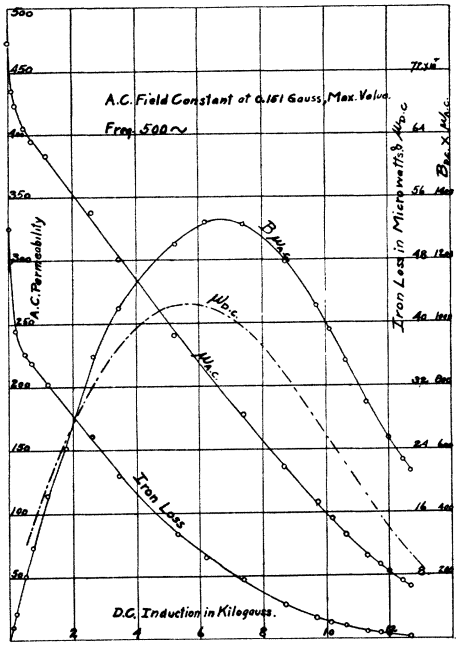

Fig. 2.

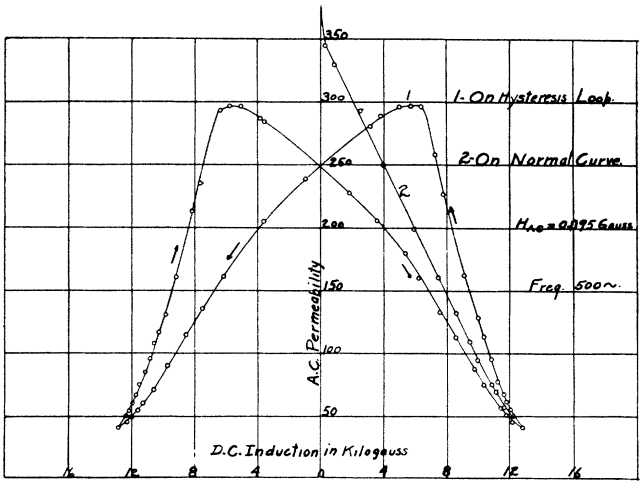

Fig. 3.

the maximum direct permeability. From the insert, in which the logarithm of the iron loss is plotted against the logarithm of the maximum alternating current induction, the iron loss is found to be proportional to the 2.16 power

of the induction. A ballistic test on the same specimen gave the value 2.13 for this exponent.

The results represented by the full-line curves of Fig. 2 were obtained from measurements with constant effective alternating current for different superposed constant inductions on the normal magnetization curve. This is a typical set taken from a number of determinations with different values of alternating current. The alternating current permeability and iron loss diminish with increasing direct current induction. Beyond an induction of 12 kilogauss the permeability is independent of the alternating field. $B\mu_{a.c.}$ reaches a maximum which comes near the maximum direct current permeability given by the dotted curve. It is of interest to note that the iron loss is relatively low at this point.

The A.C. permeability for various points on the hysteresis loop is shown in curve 1 of Fig. 3. For comparison, A.C. permeabilities on the normal curve are plotted in curve 2 of Fig. 3. The curve of iron loss is exactly similar to curve 1. Up to an induction of about two kilogauss, the permeabilities and iron loss on the normal curve exceed any value reached on the hysteresis loop. On the other hand $B\mu_{a.c.}$ attains a maximum on the descending branch of the hysteresis loop, and for an induction near the remanent value, which is about 50 per cent. above the maximum value of $B\mu_{a.c.}$ on the normal curve. But at this point the iron loss on the hysteresis loop is more than twice as great as on the normal curve.

OHIO STATE UNIVERSITY,
COLUMBUS, OHIO.

EFFECT OF STRONG ELECTROSTATIC FIELDS ON THE VAPORIZATION OF TUNGSTEN. II.

BY A. G. WORTHING.

THIS abstract covers work done in continuation of that reported on at the November meeting in Cleveland. The procedure, unchanged except in minor details, consists in noting the rate of increase in resistance of an incandescent filament in vacuo, first when in a weak electrostatic field such as to prevent thermionic emission, and second when in a strong field similarly directed. A difference in the two rates of increase is taken as evidence that vaporization is influenced by electrostatic fields.

In the work previously reported, a field strength of 80c,000 volts/cm. at the surface of the filament, resulted in no appreciable change in the rate of increase of resistance with time. Since then improvements in the kenotrons—principally the reduction in filament diameter from 0.060 mm. to 0.020 mm.—have resulted in considerably greater field strengths the maximum being about 3.2×10^6 volts/cm.

The variation of resistance with time during a test, in which a field strength of 2.7×10^6 volts/cm. and a filament temperature of 2500° K. were employed, is shown in the accompanying figure. The filament was operated throughout at 0.100,000 ampere. A steady temperature distribution was obtained after

two hours of preliminary burning. Voltage readings were begun at 11 hr. 38 min. At 12 hr. 23 min. the strong electrostatic field was applied, at 2 hr. 0 min. it was removed, etc. With one exception, the variations shown are typical of those found in each case for field strengths above 1×10^6 volts/cm. Continued operation of the filament under each of the two conditions of burning led to a straight line relation between voltage and time, and hence also between filament resistance and time. Each change from a strong to a weak field caused a sudden increase in voltage readings, followed by a rather slow asymptotic change superposed upon the final straight line change with respect to time. Reverse changes, though less evident, occurred when the strong field was applied.

A positive effect of the electrostatic field on the rate of vaporization is shown in the figure by (1) the change in slope from 2.55×10^{-3} ohms/hr. for the

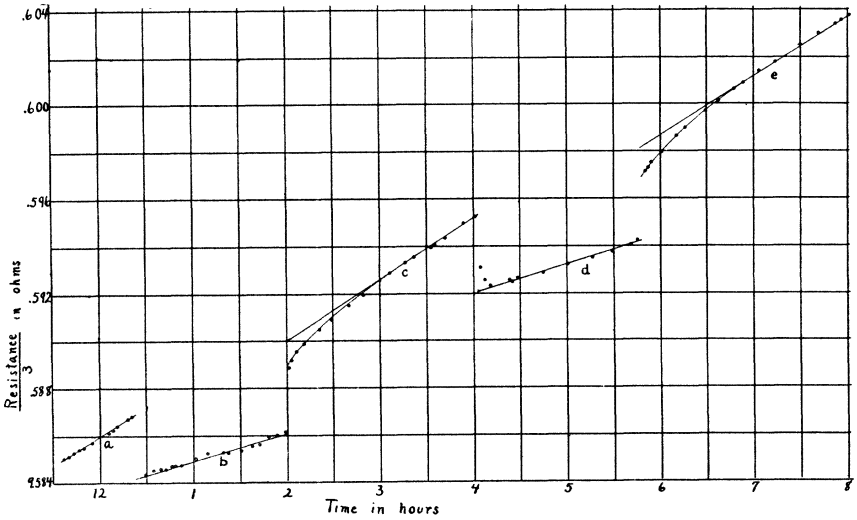

Fig. 1.

Effect of a strong electrostatic field on the vaporization of tungsten.

Kenotron No. 2.

Filament diameter 0.020 mm.

Coil diameter, 3 mm.

Potential difference between coil and filament.
a c e 30 volts.
b d 15,300 volts.
Field strength at surface of filament.
b d 2.7×10^6 volts per cm.
Rates of increase in resistance.
a c e 2.55×10^{-3} ohms per hour.
b d 1.15×10^{-3} ohms per hour.

weak field to 1.15×10^{-3} ohms/hr. for the strong field and (2) the literal shifts in the straight lines representing the resistance changes after prolonged burning in the weak field. These effects diminished with diminishing field strength in such a manner as to indicate the practical disappearance of the effects at somewhat less than a million volts per cm. On the other hand, tests with one

kenotron—the one used in obtaining the data shown in the figure—with a field of 3.2×10^6 volts/cm. showed neither of the two positive indications noted above; even though, when the strong field was applied or removed, the sudden and the slow asymptotic changes were more evident than when the lower field strengths were employed.

Work on this problem is being continued.

NELA RESEARCH LABORATORIES,
NELA PARK, CLEVELAND, OHIO,
December, 1920.

A LOW VOLTAGE CATHODE RAY OSCILLOGRAPH.

BY J. B. JOHNSON.

ATTEMPTS to make a low voltage cathode ray oscillograph with a thermionic cathode operating in a high vacuum have met with two great difficulties. These are the charging up of the fluorescent screen and glass walls of the tube, and the spreading of the beam caused by the mutual repulsion of the electrons. If, however, there is a small amount of gas in the path of the electron beam, the positive ions produced by the passage of the electrons eliminate both of these difficulties. The slowly moving positive ions build up a space charge within the beam which effectively neutralizes that of the electrons, so that the beam remains narrow and a sharp spot is produced. The ionized gas also permits the escape of the electrons from the fluorescent screen back to the anode and prevents the accumulation of disturbing surface charges.

We have made tubes on this principle having a Wehnelt cathode and operating on 500 volts. The advantages of this device over the common form of Braun tube lie in higher sensitivity, ease of operation, and reliability of performance.

With gas present steps have to be taken to guard against arcing and the injurious effects of positive ion bombardment on the cathode. This is done by making the volume of gas surrounding the electrodes very small, for which purpose the cathode and anode are enclosed in a glass tube 3 cm. long and 7 mm. in diameter. The cathode is a short oxide-coated filament bent into hairpin shape. The anode is a thin metal tube 1 cm. long and .4 mm. in diameter, one end of which is about 1 mm. from the top of the filament loop, the other end opening into the main tube towards the fluorescent screen. Between the cathode and the anode is a metal shield with a small aperture which serves to keep down the current to the outside of the anode. The small glass tube containing the electrodes is mounted within the main tube at the end opposite the screen. The gas in the tube may be the vapor from a small globule of mercury, although other gases at a pressure of about .005 mm. work equally well.

Since a comparatively large current can be obtained from the cathode without spreading of the beam, the fluorescent spot is quite brilliant, being easily

seen in daylight. A pattern traced by the spot can be photographed with an ordinary camera in from one to ten seconds. These tubes have been used to study the dynamic characteristics of the audion at radio frequencies, and are convenient indicating instruments for general laboratory use.

RESEARCH LABORATORIES OF THE
AMERICAN TELEPHONE AND TELEGRAPH CO. AND
WESTERN ELECTRIC CO., INC.

A THEORY OF THE ELECTRICAL RESISTANCE OF METALS.

BY P. W. BRIDGMAN.

A PREVIOUS theoretical discussion of the effect of pressure on resistance suggested most strongly that in metallic conduction the electrons pass through the substance of the atoms, and that the mechanism by which resistance is produced is intimately connected with the amplitude of atomic vibration. This view is here extended and given quantitative form. The classical expression for conductivity

$$\sigma = \frac{e^2}{2m} \cdot \frac{nl}{v}$$

is retained; the number of free electrons is supposed to remain constant, their velocity is taken to be that of a gas particle of the same mass and temperature, and their mean free path is supposed to be many times the distance between atomic centers. The variations of path are then computed in terms of the variations of amplitude, and thus the variations of resistance are obtained and checked with experimental results. It is shown that the theory in this form explains Ohm's law, gives the correct temperature coefficient and the most important part of the pressure coefficient, avoids the difficulty of the classical theory with reference to the specific heats, indicates a vanishing resistance at low temperatures, leaving open the possibility of super-conductivity, and retains the classical expression for the Wiedemann-Franz ratio.

A large number of new data for the effect of pressure on the resistance of a number of metals have recently been obtained, particularly for certain metals in both the liquid and the solid forms. In addition to the quantitative checks above, the new form of the theory is entirely consistent qualitatively with all the new data; in fact many of these new results seem to demand uniquely this conception of metallic conduction.

HARVARD UNIVERSITY.

TUBE EXPERIMENTS, WITH THE CATHODE REGION IN A TRANSVERSE MAGNETIC FIELD.

BY L. THOMPSON.

A TYPE of discharge tube, devised by R. H. Goddard to be used for the investigation of high vacuum spectra, has been described.[1] Two

[1] PHYSICAL REVIEW, 1917.

parallel and opposite cathode plates, separated one half inch or more, are so placed that the tube can be conveniently inserted in a magnetic field with plates perpendicular to the field. A bright cylindrical region appears between the cathodes when the field is applied, as a consequence of the great concentration of the ionizing particles and the resulting intense ionization. The path of the particles is helical, with changing pitch, in a space limited by the electric and magnetic intensities in the neighborhood of the plates.

As the magnetic field is weakened, the dark sections which surround and are very close to the cathodes, spread radially, the cylinder shortening and increasing in diameter, and eventually a dark circular center appears, of diameter varying with the value of H. For particles moving at the periphery of the dark circle, the usual relations are:

$$Hev = mv^2/r + Ee \qquad \text{and} \qquad Ve = mv^2/2.$$

If it is assumed that these which are moving circularly or spirally in the dark sections have insufficient velocity to ionize the gas, or to produce radiation, the value of V corresponding to the limiting circle (assumed thus to be a characteristic potential, ionizing or radiating) may be found if E is known. Or for a gas of known V, the electric field might be explored in the vicinity of the cathodes (varying H) and the values of V for other gases possibly then determined by comparison. Calculations for mercury vapor, with the tube used and a vacuum of the order of .0001 mm. give a value of 120 volts for E, assigning the value 10 volts to V. It is evident that the second term in the first equation cannot be neglected, as the radius of the cylinder varies considerably with the difference of potential across the tube. A low value of E might be expected in view of well-known results with high vacuum discharge in a magnetic field, and also the effect of space charge.

PIEZO-ELECTRIC ACTIVITY OF ROCHELLE SALT UNDER VARIOUS CONDITIONS.

BY J. VALASEK.

IN a previous communication, the writer has shown that the variation of piezo-electric activity with applied electric field is approximately the same as that of the derivative $\partial D/\partial E$ of the curve relating the charge D and the electric field E of the crystal used as a condenser. The latter relation being in the form of a hysteresis loop, it follows that the relation of activity to applied field depends on the direction of variation of the electric field. At zero field, accordingly, the piezo-electric response depends for a time on the previous electrical treatment of the crystal. This after-effect dies off exponentially with the time. The release of the "absorbed charge" which is though to represent a recovery from hysteresis in the polarization of the crystal follows the same kind of curve and may explain the piezo-electric fatigue.

At $-70°$ C. the piezo-electric activity is negligibly small. If the temperature is raised slowly ($\frac{1}{2}$ to 1° C. per minute) the activity stays small until

$-30°$ C. is reached. It begins to rise at $-20°$ C., increasing very rapidly, and reaching a maximum at about $-5°$ C. Then it decreases again until $+23°$ C. is reached where it rises to a second sharp maximum from which it diminishes slowly, becoming very small at $+50°$ C. The magnitude of this second maximum varies with the temperature at which heating begins.

The charging throws of the crystal used as a condenser show the same variation except that, of course, they do not tend to zero at the lower temperatures. Just in the middle of the second maximum, the crystal begins to conduct and this soon far outweighs the condenser effect. Experiments indicate that Ohm's law holds, at least approximately. Calling to mind Kelvin's theory of piezo-electricity and J. J. Thomson's theory of conduction this would indicate that the piezo-electric doublets become loosely bound and are broken up by the applied field.

When the crystal dries in phosphorus pentoxide, a white layer or dehydration slowly penetrates into the crystal causing a change in its piezo-electric behavior. The curves of activity against electric field which are already displaced from zero in the field axis, shift still farther therefrom, the maxima diminishing in magnitude. This effect is in the same direction as, and may be entirely due to, the difference of the dielectric properties of the crystal and the dehydrated layer.

PHYSICAL LABORATORY,
UNIVERSITY OF MINNESOTA,
December 10, 1920.

AN EXPERIMENT ON ELECTROMAGNETIC INDUCTION AND RELATIVE MOTION.

BY W. F. G. SWANN.

IN a recent paper,[1] the writer has discussed the relation of the moving line of force theory to the Maxwell-Lorentz theory. One of the results following from the conclusions reached in the paper relates to the case of a sphere rotating in a magnetic field about an axis parallel to the field. It was shown that the alteration of potential of a shell surrounding the sphere is entirely determined by the effect of the motional intensity resulting from the motion of the sphere in the magnetic field, and is given by

$$V = \frac{2\pi Bna^2}{3c} \cdot \frac{q_{12}}{q_{22}},$$

where B is the induction, n the frequency of rotation, a the radius of the sphere, c the velocity of light, q_{22} the capacity of the insulated system (including the electrometer), and q_{12} the coefficient of capacity between the rotating sphere and the insulated system.[2]

[1] PHYS. REV., Vol. 15, pp. 365–398, 1920.

[2] One of the a's in the former paper has been replaced by q_{12} which differs from a except when the surrounding shell has a radius large compared with a.

The significance of this result lies partly in the fact that it is true even though the rotating sphere is of iron, where, in view of the rotation of the iron, one who thought entirely in terms of moving lines of force would, presumably, have doubts as to what portion of the total induction B was to be considered as operative.

An experiment carried out to test the above conclusion resulted in the following data, giving excellent agreement with the theory. The values of $2V$ are in volts $\times 10^{-2}$, except for a factor nearly unity affecting both columns equally.

Results of Experiments on an Iron Sphere 3.2 Cms. in Radius.

No. of Obsns.	Speed R. P. M.	B C. G. S.	$2V$ (Volts $\times 10^{-2}$) Observed.	$2V$ (Volts $\times 10^{-2}$) Calculated.
8	3,260	3,860	1.02	1.02
8	3,370	4,540	1.24	1.25
8	3,280	5,060	1.36	1.36
9	3,250	6,000	1.57	1.60
4	4,830	3,860	1.59	1.52
4	4,840	4,540	1.80	1.80
4	4,850	5,060	2.01	2.00
4	4,900	6,000	2.35	2.40
2	5,600	6,000	2.73	2.75
4	6,430	3,860	2.08	2.03
4	6,460	4,540	2.45	2.40
4	6,430	5,060	2.70	2.66
5	6,430	6,000	3.17	3.16

DEPARTMENT OF PHYSICS,
UNIVERSITY OF MINNESOTA.

VERTICAL ELECTRIC CURRENTS AND THE RELATION BETWEEN TERRESTRIAL MAGNETISM AND ATMOSPHERIC ELECTRICITY.

BY LOUIS A. BAUER.

TO what extent the magnetic forces as observed on the surface of the earth can be referred to a potential, is a subject of paramount interest. The solution of the problem is of great importance both as regards the constitution of the so-called permanent magnetic field of the earth and the systems giving rise to the manifold variations to which the terrestrial magnetic field is continually subject.

Any electric currents circulating above or below the earth's surface in concentric layers, *i.e.*, parallel to the surface, will give rise to magnetic forces which may be represented by a potential. Electric currents, on the other hand, cutting the earth's surface, produce, in general, a mixed magnetic system; the horizontal components of such currents produce a magnetic potential, whereas,

the vertical components cause magnetic forces which cannot be referred to a magnetic potential. As known, the test of the existence of a potential is that the line-integral of the magnetic force taken around a reëntrant curve or circuit on the earth's surface shall vanish. If the line-integral does not vanish, and its departure from zero cannot be explained by error of observation, or local magnetic disturbance in the region of the circuit, then the existence of a non-potential is revealed; from the magnitude and sign of the integral we may then determine the strength and direction of the electric currents passing perpendicularly through the area inclosed by the circuit.

The author published investigations concerning vertical currents in 1897 and again in 1904, based on the computations of line-integrals, taking as circuits of the earth parallels of latitude and using data scaled from various world magnetic charts. The method of computation eliminated, or reduced to a minimum, the effect of systematic errors in these charts. A rather interesting and suggestive distribution of vertical electric currents over the earth was found for the region investigated, 60° North to 60° South. The average strength of the vertical currents turned out to be one fortieth of an ampere per square kilometer, which is about eleven thousand times that found from atmospheric-electric observations.

At the Washington meeting in April, 1908, of the Society, the results were communicated of a third investigation on vertical currents, dependent this time upon the 1905 magnetic charts for the United States, which is the largest land area over which a detailed and carefully-conducted magnetic survey has been made. The results of line-integrals computed for various large circuits within the United States again revealed apparently vertical currents on the order of ten thousand times that from atmospheric-electric measurements.

The results of the present investigation are based on line integrals computed for circuits of the earth along parallels of latitude from 60° North to 60° South, as dependent upon data scaled from the most recent magnetic charts constructed with the aid of the new data obtained by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, both on land and at sea. Some corrections have been applied to the data thus scaled from the charts on the basis of the observations obtained on the present cruise of the *Carnegie*. The line-integral was also computed for the *Carnegie's* circumnavigation cruise in the Sub-Antarctic regions, December, 1915, to April, 1916.

The results from the new computations were shown in slides exhibited. The circulation of the present vertical electric currents agrees in general with that obtained by the author previously. If the asymmetries about the equator are eliminated by taking mean results of corresponding parallels north and south, we may say that there would be downward currents of negative electricity in higher latitudes and upward in lower latitudes. The average strength of these currents, for the region considered, would be about one thirty-fifth of an ampere per square kilometer—once more on the order of ten thousand times that from atmospheric-electric observations. The actual current-density in certain regions may be as much as one eighth ampere per sq. km.

In order to correlate the vertical currents observed in atmospheric electricity with those resulting from the line integrals of the magnetic force, it will be necessary not only to account for the outstanding factor of 10^4 but also to explain the variation in sign. The air-earth conduction current of atmospheric electricity is assumed to consist of currents of positive electricity streaming downwards all over the earth, whereas the currents obtained from the magnetic observations, as shown by the slides, proceed downward over certain regions and upward over others. The integral of the latter currents may vanish if taken over the entire earth, whereas the atmospheric-electric current corresponds to a continual replenishing of the earth's negative charge amounting to about 1,000 amperes. Further research will be necessary before more definite information can be given as to possible correlations between the two sets of currents.

The variations in vertical currents during the solar eclipse of May 29, 1919, as obtained from the line integrals of magnetic force, agreed qualitatively with the variations in the vertical current shown by the atmospheric-electric observations during totality at Sobral, Brazil. However, once more, the results from the two sets of observations, magnetic and electric, do not agree quantitatively, the outstanding factor being on the order of 3×10^3.

CARNEGIE INSTITUTION,
WASHINGTON.

THE ECLIPSE MAGNETIC SYSTEMS OF MAY 29, 1919.

BY LOUIS A. BAUER.

WITH the aid of the magnetic data observed by the various expeditions of the Department of Terrestrial Magnetism during the solar eclipse of May 29, 1919, and by coöperating observatories, an analysis was made of the systems of forces which produced the observed magnetic effects.

The vectors showing the combined effect in declination and horizontal intensity invariably were found to point approximately towards a focus located in the vicinity of the shadow cone and moving with it over the earth as the eclipse progressed from station to station.

With the aid of the vertical-intensity effects, it was found that the eclipse magnetic systems were composed of an external and an internal system of forces. The analysis in general shows that the eclipse magnetic systems of May 29, 1919, have characteristics analogous to those exhibited by the systems causing the solar-diurnal and the lunar-diurnal variations of the earth's magnetism.

It was furthermore found that the observed magnetic effects could not wholly be referred to a potential; there was an appreciable outstanding portion which clearly showed the existence of vertical electric currents passing through the surface of the earth in the region of visibility of the eclipse. The line integrals of the magnetic force were computed for circuits of various dimen-

sions, inclosing Sobral, Brazil, where atmospheric-electric observations were made by the expedition of the Department of Terrestrial Magnetism. The slides shown exhibit the results of these computations. There was a drop during totality of the eclipse in the vertical electric current resulting from the magnetic observations, corresponding with the drop in the vertical current shown by the atmospheric-electric observations. The strength of the vertical current resulting from the magnetic observations was about 3,000 times that from the atmospheric-electric measurements.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON.

ANHYSTERETIC CURVES OF IRON-CARBON ALLOYS MADE WITH A BRAUN TUBE.

BY C. W. WAGGONER AND F. A. MOLBY.

THE anhysteretic character of magnetization curves in which the alloy is subjected to longitudinal magnetic fields during the time the static hysteresis curves were being made, was the subject of a former paper.[1] Certain errors in the method used led the present writers to repeat the study of the hysteresis of a series of iron-carbon alloys under different conditions.

1. Hysteresis curves were made without the longitudinal 60-cycle A. C. field and then curves with the A.C. field in which the A.C. field was introduced and then removed before each observation in the step by step method. In all cases the A.C. field was equal to or greater than the D.C. magnetizing field. Curves taken in this latter manner show no hysteresis even in the case of samples containing 1.13 per cent. carbon.

2. Curves were taken of the complete loop of magnetization with continuously superimposed A.C. magnetization as well as the varying D.C. excitation. Except in the case of very high carbon steels there seems to be no residual or hysteresis area. In the high carbon samples there is a bare trace of this residual area but the reduction in area of the static loop with the applied 60-cycle A.C. field was far greater than that found by using the method described in the previous paper referred to above.

WEST VIRGINIA UNIVERSITY.

POSITIVE RAY ANALYSIS OF MAGNESIUM.

BY A. J. DEMPSTER.

USING the method described in the PHYSICAL REVIEW for April, 1918, p. 316, magnesium has been analyzed into three isotopes with atomic weights 24, 25 and 26. The components at 25 and 26 are present in approximately equal amounts, and the one at 24 is about six times as strong as either of the others. The average atomic weight agrees closely with that given by the chemists.

UNIVERSITY OF CHICAGO.

[1] Waggoner and Freeman, Gen. Elec. Rev., Vol. XXI., 1918, p. 143.

PRESSURE SHIFTS IN A CALCIUM ARC.

BY HENRY G. GALE AND L. F. MILLER.

SINCE the discovery by Goos[1] of the so-called pole-effect in arc spectra, considerable doubt has been felt as to the significance of pressure shifts of spectral lines. Some results on the pole-effect in a calcium arc[2] were obtained at the Ryerson Laboratory several years ago. Measurements of pressure-shifts of the same lines in a similar arc have just been completed.

In both sets of experiments the arc was formed between electrodes of metallic calcium. The poles were about 9 mm. in diameter and the current was kept at 4 amperes on a 110-volt D.-C. circuit. The following table gives the new pressure-shifts as measured by Mr. Miller, and the pole-effect change in wave-

TABLE.

Series Group.

λ	Press Shift.	Pole-Effect. +	Pole-Effect. −	λ	Press Shift.	Pole-Effect. +	Pole-Effect. −
p 6,499.8	.002	.005	.000	*T*1₄ 4,456.1			
6,493.9	.001	.003	.000	4,454.9			
6,449.9	.001	.003	−.003	4,435.1	−.001	−.003	.001
4,302.6	.000	−.001	.000	4,435.1			
4,283.1	−.001	−.003	.000	4,425.6			
*SI*₂ 5,041.9	.015	.024	−.003	*T*1₅ 3,644.8			
4,527.1	.027	.036	.008	3,644.5			
*SI*₃ 4,878.3	.031	.045	.000	3,631.1	−.029	−.037	.005
4,355.4	.068	...	...	3,630.8			
*t*₄ 4,586.1				3,624.1			
4,581.6	.030	.040	−.004	*T*1₆ 3,361.9			
4,578				3,350.2	−.054	−.050	.011
*t*₅ 4,098.6				3,344.4			
4,095.0	.044	.055	−.013	*T*2₃ 6,162.4			
4,092.7				6,122.4	.012	.017	.000
T 4,318.8	−.001	−.003	.001	6,102.9			
4,299.1	−.001	−.003	.000	*T*2₄ 3,973.8			
4,289.5	−.000	−.001	.001	3,957.2	.016	.024	−.003
*P*₂ 3,737.1	.008	.012	.001	3,949.1			
3,706.1				*T*2₅ 3,487.7			
*P*₁ 3,181.4	.013	.008	.003	3,474.9	.041	.030	−.003
3,179.4	.013	.008	.001	3,468.6			
3,158.9	.014	.010	.000	*T*2₆ 3,286.2			
H 3,968.6	.001	.002	.000	3,274.8	.046	.034	−.005
K 3,933.8	.001	.002	.000	3,269.3			

[1] Astrophysical Journal, 38, 141, 1913. [2] Astrophysical Journal, 43, 161, 1916; 44, 65, 1916.

Non-Series Group.

λ	Press Shift.	Pole-Effect. +	Pole-Effect. −	λ	Press Shift.	Pole-Effect. +	Pole-Effect. −
6,471.8	.002	.004	.000	5,513.1	−.023	−.032	−.003
6,462.7	.001	.003	−.002	5,349.6	.005	.007	−.003
6,439.3	.001	.000	−.001	5,270.4	.004	.018	.000
6,169.8	.012	.017	.000	5,265.7	.003	.016	.000
6,169.3	.013	...	...	5,264.4	.010	.014	.000
5,857.7	.022	.032	.001	5,262.4	.010	.016	.000
5,603.1	.006	.011	−.003	5,261.9	.011	.016	.000
5,601.1	.006	.011	−.003	5,189.0	−.003	−.007	.003
5,598.6	.003	.008	−.003	4,685.4	−.009	−.012	.002
5,594.6	.007	.011	−.001	4,307.9	−.001	−.001	.000
5,590.3	.005	.009	−.003	4,240.5	...	...	...
5,588.9	.005	.008	−.004	4,226.9	.018	.005	.000
5,582.1	.005	.009	−.003				

length as measured by Mr. Whitney in 1916. The pressure-shifts were the changes in wave-length observed for a change in pressure from 5 cm. to one atmosphere. The middle of a horizontal arc, about 4 mm. long, was projected, with an enlargement of about four diameters, on the slit of a 21 ft. concave grating spectroscope.

The table gives the series classification, the wave-length, the pressure-shift, pole-effect from center of arc to + pole, and center to − pole.

The agreement between pole-effect and pressure-shift points strongly to the intimate relation between these effects, as has been suggested frequently.

It is not possible to say whether the change in the character of the arc produced by a change in pressure causes a "pole-effect" change in wave-length at the middle of the arc, or whether the pressure change *per se* causes the shift. In any case, the table gives the changes at the middle of a 4 ampere arc when the pressure is changed by approximately one atmosphere.

UNIVERSITY OF CHICAGO.

THE LUMINESCENCE OF ZINC OXIDE ABOVE THE RED HEAT.

BY E. L. NICHOLS.

THIS oxide, when pure, is not photo-luminescent nor does it respond to X-rays. It is, however, susceptible to excitation by the hydrogen flame[1] with the development of two bands:

1. A red band which appears when the oxide is heated to 568° and which on further heating to about 700° is displaced by a yellow green band.

2. A yellow-green band.

The latter disappears at about 940°.

This is a special case of the effect described in recent papers. It is mentioned here because measurements of the brightness of luminescence with an optical pyrometer show:

[1] Nichols and Wilber, "On Flame Excitation of Luminescence," PHYSICAL REVIEW, (2), XVII., Feb., 1921.

1. That the luminescence of the zinc oxide reached a maximum of brightness at a temperature somewhat above 800° when it was about 11.4 times as bright as copper oxide at the same temperature and 115 times as bright as zinc oxide of the same temperature when not excited to luminescence.

2. That the relative emissivity of zinc oxide referred to that of copper oxide as a convenient standard falls to a minimum at the temperature of greatest luminescence and rises rapidly as the luminescence disappears with increasing temperature.

3. That the electric resistivity of zinc oxide, as shown by certain unpublished data obtained by Professor C. C. Bidwell and to which he permits me to refer in this connection, undergoes a sudden change within this temperature range of luminescence indicative of some molecular transformation.

This last named relation is deemed to be of special significance in that it may indicate that under conditions where molecular bonds are undergoing a

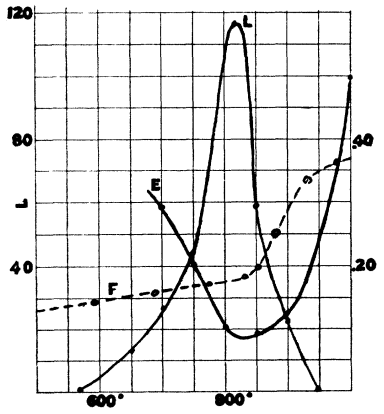

Fig. 1.

rearrangement substances are rendered susceptible to the excitation of luminescence.

In the accompanying diagram curve L shows the brightness of zinc oxide under flame excitation compared with its brightness when unexcited. Curve E is the relative emissity and F is a function of the resistance of the oxide which is linear everywhere except for the temperature range beginning at about 850°.

PHYSICAL LABORATORY OF CORNELL UNIVERSITY,
December, 1920.

SOME ADDITIONAL MEASUREMENTS OF WAVE-LENGTHS IN THE CALCIUM ARC IN VACUO.

BY GEO. V. MCCAULEY.

IN order to check the grating measurements of Crew and McCauley[1] and verify the differences existing between their values and those of Holtz,[2]

[1] Astrophysical Journal, 39, 29, 1914.

[2] Zeitschrift für Wissenschaftliche Photographie, 12, 101, 1913.

measurements were undertaken with the Fabry and Perot interferometer in conjunction with a Hilger fixed arm spectroscope.

The same source as was used by Crew and McCauley was employed at about one centimeter of mercury pressure. Measurements were made on 46 Ca lines between 4283 λ and 6500 λ. On 44 of these lines there exists a mean divergence from Crew and McCauley's values of .0067 Å.; while the mean divergence from the measurements of Holtz on these same lines is .0168 Å.

One new line 4581.466 Å. was observed.

CORNING GLASS WORKS,
CORNING, NEW YORK.

APPROXIMATE COMPUTATIONS OF X-RAY ABSORPTION FREQUENCIES.

BY WILLIAM DUANE.

THREE general laws—the acceleration law, the angular momentum law and the frequency law—form the basis of Bohr's theory of radiation. These laws do not determine the distribution of electrons in the various orbits. In order to calculate radiation frequencies this distribution must be known.

A number of scientists have shown that it is possible to choose the distribution of electrons in the orbits in such a way that the equations deduced from the theory represent some of the observed frequencies of X-rays with considerable accuracy.

At the meeting of the A.A.A.S. in December, 1919,[1] I presented a set of computations of the K critical absorption frequencies characteristic of the chemical elements. These frequencies have been measured for almost all of the chemical elements from magnesium (atomic number 12) to uranium (atomic number 92). In making these computations I did not choose the distribution of electrons to fit the frequencies. I used what may be called the chemical distribution. The computed values differ from the observed values by less than the corrections due to the mutual influence of electrons in different orbits on each other. In these calculations the orbits were supposed to lie in planes through the nucleus. In the present paper computations of the same kind are presented for the case in which most of the orbits lie in parallel planes that do not pass through the nucleus. This gives a volume distribution of electrons.

Since the early history of electron theory the numbers of electrons in the various orbits (or groups into which the electrons in an atom may be subdivided) have been supposed to correspond to the intervals between the atomic numbers of the chemically inert gases. The atoms of these gases have groups that are completely filled up. The atomic number intervals are

$$2,\ 8,\ 8,\ 18,\ 18,\ 32.$$

As is well known the intervals may be written

$$2 \times 1^2,\ 2 \times 2^2,\ 2 \times 3^2,\ 2 \times 4^2.$$

[1] Science, May 21, 1920.

In making the computations I have interpreted this to mean that the number, n, of electrons in a completed orbit equals the square of the quantum number, τ, associated with that orbit, $n = \tau^2$; and further that there are two orbits in each group. Each completed group, therefore, contains $2\tau^2$ electrons. Thus there are two orbits with the quantum number $\tau = 1$, each of which contains one electron, the plane of each orbit passing through the nucleus. These two electrons must revolve in opposite directions or in planes inclined to each other, otherwise they would travel in the same orbit. Corresponding to the second atomic number interval there are two 2 quantum orbits in parallel planes that do not pass through the nucleus, and each orbit contains 4 electrons. These, also, must revolve in opposite directions, else they would combine (for elements of high atomic number) to form a ring of 8 electrons. Outside of these electrons there are two other 2 quantum orbits corresponding to the third atomic number interval, each containing 4 electrons and so forth. This arrangement gives a volume distribution of electrons quite similar to the layers and shells of the Lewis-Langmuire static atom.

In order to compute a K critical absorption frequency we calculate the amount of energy required to remove either one of the 1 quantum electrons to a point outside of the atom. This can be done by using the equations of Bohr's theory to calculate the energy of the atom with the two 1 quantum electrons in place, and then to calculate the energy when one of them has been removed. The difference between the two equated to $h\nu$ gives the required frequency, ν.

The largest term in the computation represents the energy required to remove the electron against the attraction of the nucleus. From this must be subtracted a correction term (amounting to 15 or 20 per cent.) due to the influence of the electrons. To compute this I have used an approximate expression for the force exerted by one ring of electrons on the ring parallel to it and of the same size. To calculate the influence of orbits on each other that are not of the same size would require an enormous amount of labor. To estimate the effect on the calculated frequencies of this influence I have assumed it to be about the same as it would be, if the orbits lay in the same plane. The correction to the value of ν due to this influence averages 2 per cent. for the different atomic numbers.

With these approximations the computed values of the K absorption frequencies for 14 chemical elements ranging in atomic number from 12 to 92 equal the observed values to within 1 or 2 per cent., as the lantern slide indicates.

The fairly close agreement between theory and experiment becomes very striking, when we remember that none of the quantities entering into the computations comes from X-ray measurements alone. The equations do not contain a single undetermined constant. These quantities are (*a*) the Rydberg fundamental frequency, which is known with very great accuracy, and (*b*) the electron's charge, Planck's action constant and the velocity of light. The three quantities (*b*) enter into the equations only as a correction term due to the change of the electron's mass with its velocity.

Various corrections have been omitted in the computations—for instance the magnetic influence of the electrons on each other, the question as to whether the electron must be removed to an infinite distance from the atom, or only to its periphery, the question as to whether some of the electrons may not be forming bonds with other atoms, and may, or may not, under these conditions contribute to the energy changes, etc.

It appears that both the coplanar distribution of electrons previously reported on and the present volume distribution enable us to calculate the K absorption frequencies fairly well. There are also other distributions, corresponding to different interpretations of the atomic number intervals, that work almost, if not quite as well as these. An important point in the theory is that there are 2 electrons with 1 quantum, 16 electrons with 2 quanta, 36 electrons with 3 quanta and 32 electrons with 4 quanta.

By arbitrarilly shifting electrons about in the outer orbits it would be possible to make the theory agree with the facts to almost any degree of accuracy. This, however, would not mean very much.

Computations of the L and M absorption frequencies present very great difficulties.

In coplanar orbits elliptic L orbits are difficult to admit. They would interfere with the K orbits. In the volume distribution, however, there is room for orbits of some such shape as that of ellipses. They would not be plane orbits, but orbits in space of three dimensions. The three dimensions may give an explanation of the three critical absorption frequencies observed in the L series. Plane orbits that may be either ellipses or circles explain only two of these frequencies.

HARVARD UNIVERSITY.

THE EVIDENCE REGARDING THE SO-CALLED "J" RADIATION IN THE CHARACTERISTIC X-RAY SPECTRA OF THE ELEMENTS.

BY F. K. RICHTMYER

IN a previous communication[1] it was shown that, contrary to the observations of Barkla and White,[2] there were no discontinuities in the X-ray absorption of aluminum and water at wave-lengths, $\lambda = .37$ Å. and $\lambda = .39$ Å. respectively, and hence that there is no basis for the conclusion that these elements have "J" radiations at these wave-lengths. This agrees with results obtained by Duane and Shimizu[3] on the radiation from an aluminum target.

After reporting the above, the present writer's attention was called to a paper by Williams[4] who concluded that the discontinuity in the absorption curve for Al was at $\lambda = .49$ Å., instead of at .37 Å. as found by Barkla and

[1] Richtmyer and Grant, PHYS. REV., XV., 547 (1920).
[2] Barkla and White, Phil. Mag., 34, 270 (1917).
[3] PHYS. REV., XIII., 289 (1919).
[4] Proc. Roy. Soc., 94, p. 576.

White. Williams also concluded that a discontinuity in copper existed at .448 Å. A very careful investigation of the absorption curves of these two elements at these wave-lengths fails to reveal any discontinuities as great as one per cent. The apparent low precision in Williams' work does not seem to justify his conclusion.

Still later Dauvillier[1] reports a discontinuity in the absorption curve of aluminum at $\lambda = .358$ Å. Using his own and Barkla and White's data on carbon and oxygen he predicts that there should be a "J" emission of boron at $\lambda = .42$ Å., although, using boron as a target he fails to reveal any characteristic radiation in the region $.2 < \lambda < 1.0$ Å. Dauvillier concludes that although the "J" absorption exists, the "J" radiation is too faint to measure. A discontinuity for bromine was observed at $\lambda = .227$ Å.

Dauvillier refers to a paper by de Broglie[2] in which reference is made to an absorption band in silver at $\lambda = .178$ Å. If, according to Dauvillier, the square root of frequencies of these J radiations for Ag, Br and Al be plotted against N a curve similar to Mosley's curves for the K and L series results, passing through one of the gamma rays of Rad. C as observed by Rutherford and Andrade.

Such a graph would predict J absorptions in Cu and Mo at .250 Å. and .196 Å. respectively.

The present writer has studied the absorption of all of the above named elements, with the exception of bromine, over the critical ranges where J radiations have been observed or would be predicted by a relation similar to Mosley's for the K series. It has been shown[3] that the mass absorption coefficient, μ/ρ, is a linear function of the cube of the wave-length. Data gives a precision of approximately 1 per cent. *In no case* is there a break in the curve between μ/ρ and λ^3 at the critical wave-lengths mentioned. *It may therefore be concluded that within 1 per cent., there are no discontinuities in absorption suggestive of J radiations.*

The break at $\lambda = .358$ in the energy curve of an X-ray tube with an aluminum filter interposed, as found by Dauvillier, is obviously due to the K absorption of the iodine in the ionization chamber, as pointed out by Duane and Shimizu.

CORNELL UNIVERSITY.

THE SPECTRUM OF HELIUM IN THE EXTREME ULTRA-VIOLET.

BY HUGO FRICKE AND THEODORE LYMAN.

FORMER work on the spectrum of helium has shown that but two lines, one at 1,640 Å.U. and the other near 1,215 Å.U., can be attributed with any certainty to this gas in the Schumann region. A number of observers

[1] Ann. de Physique, 13, p. 49 (1920).

[2] Journal de Ph., Vol. 6, p. 161 (1916).

[3] Richtmyer and Grant, loc. cit., also Richtmyer, Proc. Am. Phys. Soc., PHYS. REV., Feb., 1921.

have found a resonance potential in helium corresponding to a wave-length of about 600 Å.U.; the present paper deals with an attempt to find this line.

A small vacuum spectroscope was employed containing a grating of but 20 cm. radius; a continuous current of about 30 milliamperes flowing through a quartz discharge tube was used; the electrode consisted of a hollow cylinder similar to that described by Paschen. The region investigated lay between 0 and 1,200 Å.U.

Under these conditions the strongest line in the region occurs at 585 Å.U., it is accompanied by five or six fainter lines almost certainly due to impurities.

It is interesting to note that the wave-length 585 corresponds with the resonance potential determined by Franck and Knipping rather than with the results of other observers.

HARVARD UNIVERSITY.

THE ABSORPTION OF LIGHT BY MIXTURES OF INORGANIC SALTS.

BY E. F. GEORGE.

THE object of the present work was:

1. To investigate the effect of one salt upon the absorption of light by another salt with which it is mixed in an aqueous solution.

2. To test the validity of Jones' "Solvate Theory" by the results of the above investigations.

3. To measure the absorption of alcoholic solutions of certain organic salts.

4. To study the effect of temperature upon absorption.

A Hilger spectrometer with a Nutting photometer box was used. In most cases the extinction coefficient was computed and plotted against the wave-length.

The following conclusions are drawn:

1. The effect of one salt in changing the absorption of light by another salt seems to be greater in chlorides than in nitrates or sulphates.

2. The temperature effect appears to be greater in chlorides than in nitrates or sulphates.

3. Ostwald's theory that the colored ion is alone effective in the absorption of light seems to break down, as Jones has already pointed out.

4. The ratio of the absorption of the mixture to the sum of the absorptions of the component parts, when plotted against the wave-length, has a minimum value somewhere between $\lambda = 5{,}100$ and $\lambda = 6{,}100$ Å.U.

5. The change in absorption appears to be greatest in solutions containing one or more of the magnetic elements. This may possibly mean that some of the effect is due to frequency changes arising from magnetic forces.

6. Certain salts which have little tendency to form hydrates very often cause greater changes in absorption than some other salts which have a great avidity for water. This is diametrically opposed to the "Solvate Theory."

These investigations were carried out at Ohio State University at the suggestion and under the supervision of Professor Alpheus W. Smith.

WEST VIRGINIA UNIVERSITY.

CHARACTER OF THE SPECTRA PRODUCED BY HIGH POTENTIAL SPARKS IN A VACUUM.

BY EDNA CARTER.

PHOTOGRAPHS were obtained of the "hot spark" spectra of calcium, magnesium, cadmium, titanium and iron. They were made for the most part with a 20 cm. focus concave grating. The iron spectrum was photographed in the region λ 3,800 to λ 6,600 by using an æscoline filter and films bathed in the Wallace three-dye solution.

The spectra of calcium, magnesium and cadmium resemble closely the usual spark spectra of these elements. In the titanium spectrum many arc lines are retained which are faint or absent in the spark in air, but the enhanced lines are also present in considerable intensity. Although the iron spectrum seems to be very much like the arc spectrum of iron in general appearance, still the low temperature lines are absent, the lines which are stronger at the poles of the arc are relatively intense and certain enhanced lines such as λ 5,018 and λ 5,316, which do not appear in the arc, are found in the "hot spark" spectrum. Of all these metals the iron required the highest potential gradient between the electrodes for the production of this vacuum spark.

In general, the spectra obtained from this source seem to be intermediate between the arc and the spark spectra and to resemble most closely the spectra produced by cathode ray bombardment in a high vacuum.

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INFRA-RED SPECTRA OF ISOTOPES.

BY F. W. LOOMIS.

IT is shown that only minute differences are to be expected in the visible and ultra-violet spectra of isotopes, since these spectra are caused by vibrations of electrons in the outer shells of the atoms and are only affected by the masses of the nuclei to the extent that they enter into the expression, $m = m_1 m_2/m_1 + m_2$, for the effective mass of the vibrating electrons. Such differences, of the order of 0.004 Å., have recently been found by Aronberg and by Merton between the wave-lengths of corresponding lines in the spectra of lead isotopes. Much greater differences should occur in the infra-red absorption bands of such isotopic substances as HCl, since in this case the mass of the nucleus is much more nearly equal to the vibrating mass, the hydrogen nucleus, and has a correspondingly greater effect on its effective mass. The

frequency with which the hydrogen nucleus vibrates towards and away from the chlorine atom is proportional to $1/\sqrt{m}$. Aston has shown that chlorine consists of isotopes of atomic weights 35 and 37. The corresponding values of m, the effective mass of the hydrogen nucleus, are 35/36 and 37/38, which differ by 2 parts in 1,330. Consequently the vibration frequency of HCl^{35} should be 1 part in 1,330 greater than that of HCl^{37} and lines in the absorption spectrum of HCl should occur as doublets separated by 1/1,330 of their wave-length. Since the average atomic weight of Cl is 35.46, the atoms of Cl^{35} must be over 3 times as numerous as those of Cl^{37} and the doublet lines of longer wave-length should be the fainter.

The most accurate measurements of the HCl infra-red absorption spectrum were published by Imes in the Astrophysical Journal, Vol. 50, p. 251. The "fundamental" band at 3.46 μ was not sufficiently resolved to show the satellites but each line of the "first harmonic" band at 1.76 μ shows a satellite on the long wave side separated by an average interval of 14 ± 1 Å. The theoretical separation is $1.76\,\mu/1{,}330 = 13$ Å. Clearly these satellites are the lines due to the heavier isotope of chlorine. Imes also published curves on HBr but not sufficiently resolved to show the expected doublets. His curves for HF would show doublets if any appreciable quantity of isotopes were present. The absence of doublets confirms Aston's conclusion that fluorine is pure.

NEW YORK UNIVERSITY.

THE ABSORPTION SPECTRA OF ORTHO-CRESOLSULPHONPHTHALEIN.

BY W. R. ORNDORFF, R. C. GIBBS, M. SCOTT AND S. D. JACKSON.

MEASUREMENTS covering a range of natural frequencies from 40×10^{13} to 120×10^{13} show that ortho-cresolsulphonphthalein and other related compounds have in neutral aqueous solutions two absorption bands and that the addition of either acid or alkali results in the disappearance of one of the bands and the appearance of two new absorption bands one on each side of the position of the band that disappears. The other band of the neutral solutions seems to be modified by the addition of acid, but with the addition of alkali it also disappears and a new band with lower frequency appears. In the case of dilute *alkaline* solutions the new type of absorption is not stable but reverts more or less rapidly to the two band absorption found in the corresponding neutral solution. These changes and reversions indicate that in the neutral aqueous solutions the carbinol and hydrate forms of the phthalein are present and that on the addition of either acid or alkali a salt having a quinoid structure is formed.

CORNELL UNIVERSITY.